DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers

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Technical Letter
No. 1110-2-533 — 30 September 1994

Engineering and Design
LIFELINE REPORT NO. 1, SYSTEMS AT RISK FROM EARTHQUAKES,
HYDROELECTRIC POWER PLANT FACILITIES

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LIFELINE REPORT NO. 1, SYSTEMS AT RISK FROM EARTHQUAKES, HYDROELECTRIC POWER PLANT FACILITIES

1. Purpose

This engineer technical letter (ETL) provides information on the vulnerability of electrical power-generating equipment and power plant facilities equipment to earthquake ground motions.

2. Applicability

This ETL applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works responsibility.

3. References

a. Executive Order 12699.

b. Public Law 101-614, National Earthquake Hazards Reduction Program (NEHRP) Reauthorization Act.

c. Earthquake Hazard Reduction Act of 1977.

d. ER 1110-2-1806, Earthquake Design and Analysis for Corps of Engineers Projects.

e. ETL 1110-2-301, Interim Procedure for Specifying Earthquake Motions.

f. ETL 1110-2-303, Earthquake Analysis and Design of Concrete Gravity Dams.

g. ETL 1110-2-339, Seismic Design and Evaluation of Intake Towers.

h. CEGS-13080, Seismic Protection for Mechanical Electrical Equipment.

i. ANSI A17.1, National Elevator Code, American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

j. ANSI A58, Minimum Design Loads for Buildings and Other Structures, American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

k. NFPA 13, Standards for the Installation of Sprinkler Systems, National Fire Protection Association, P.O. Box 9146, Quincy, MA 02269.

l. Uniform Building Code, International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, CA.

4. Background

a. *Lifelines*. Corps of Engineers lifelines are those systems and components of Corps projects that are critical to onsite emergency response and to the conveyance of water, power, and other essential commodities to communities in times of a natural disaster. An earthquake is the most likely disaster that would lead to lifeline disruption.

b. *Past practices*. Past practices for the design of mechanical and electrical equipment at Corps projects, in most instances, did not consider how this equipment should be anchored and configured to protect it from the damaging effects of earthquake ground motions.

c. General objectives. Objectives are to identify the most critical lifelines in terms of vulnerability and impact on project performance, and to provide seismic protection for the most critical lifelines in the most cost effective manner.

5. Action

a. Immediate action. New contracts involving work for hydroelectric power plant facilities should include appropriate provisions for the seismic protection of mechanical and electrical equipment. Military guide specification CEGS-13080 can be used for that purpose.

b. Long-term actions. Walk-through inspections should be conducted on all Corps projects in seismic zones 2A, 2B, 3, and 4 (see Table A-1, Appendix A) in conjunction with periodic inspections. These walk-through inspections should concentrate on vulnerable areas cited in Appendix B. The following items, because of their importance to onsite emergency response, should be properly secured or anchored:

(1) Batteries required for emergency power, monitoring, and control.

(2) Emergency engine generators.

(3) Essential communications equipment.

FOR THE DIRECTOR OF CIVIL WORKS:

PAUL D. BARBER, P.E.
Chief, Engineering Division
Directorate of Civil Works

2 Appendices
APP A - Lifeline Report No. 1
APP B - Guidelines for Evaluating the Seismic Vulnerability of Lifelines and Ancillary Systems Required for the Operations of Dams and Mitigation Measures for Reducing Seismic Vulnerability

Appendix A: Lifeline Report No. 1

A-1. Introduction

a. Overview. Corps of Engineers civil works projects play an important role in the recovery of communities following a major earthquake. The nation's inland waterway system, which is operated and maintained by the Corps, will be essential in the aftermath of a earthquake for the delivery of materials and equipment needed for the recovery of devastated communities. Hydropower-generating facilities at Corps projects provide electrical power that will be important to postearthquake recovery. Corps projects also include reservoirs and outlet works that supply water to communities. Water supplies will be needed for postearthquake recovery and to control fires resulting from gas mains ruptured by earthquake ground motions.

b. Objectives. Lifeline Report No. 1 is the first of a series of three reports on Corps of Engineers civil works lifelines. These reports:

(1) Identify Corps lifelines.

(2) Assess lifeline vulnerability to earthquakes.

(3) Identify mitigation measures to correct deficiencies and improve earthquake resistance.

(4) Establish priorities for mitigation and remedial work.

(5) Recommend funding levels and schedules for the implementation of mitigation and remedial work.

c. Importance of Corps lifelines. Corps lifelines are not only those facilities important to post-earthquake recovery of communities, but also include facilities required for emergency response to earthquake damage at projects, and facilities required for continued operation of critical project functions. Lifelines include those facilities essential in providing:

(1) Electrical power for the emergency operation of spillway gates and reservoir outlet works required to lower reservoir levels or to prevent overtopping.

(2) Electrical power for postearthquake recovery of communities.

(3) Communication for project operation and systems operation during an emergency.

(4) Transportation systems (project roads and bridges) required for personnel and equipment access to critical project features during an emergency.

(5) Transportation systems, such as the inland waterway, required for the transportation of supplies and equipment needed for postearthquake recovery of communities.

(6) Water needed for emergency response and postearthquake recovery of communities.

A-2. Corps Lifeline Reports

a. Purpose and schedule. Three lifeline reports will be prepared describing the vulnerability of typical Corps projects to earthquake ground motions. These reports form the basis for an engineer regulation which provides direction for an overall Corps of Engineers lifeline evaluation and mitigation program. The program's purpose is to reduce earthquake vulnerabilities and comply with the national goals and standards of Public Law (PL) 101-614. Lifeline Report No. 2 will be completed by the end of FY 94, and Lifeline Report No. 3 by the end of FY 96. Lifeline Report No. 1 describes the overall lifeline evaluation program and assesses in general terms the vulnerability of Corps power-generating facilities, emergency power systems, and communication systems to the damaging effects of earthquakes. Lifeline Report No. 1 also recommends action to correct deficiencies associated with mechanical, electrical, and communication systems. Lifeline Report No. 2 will assess the vulnerability of Corps transportation systems (i.e., the inland waterway system and project roads and bridges) to the damaging effects of earthquakes. Lifeline Report No. 3 will evaluate the vulnerabilities of Corps water supply systems critical to communities for emergency response and postearthquake recovery. Report No. 3 will also report in detail

and summarize the earthquake evaluations performed to date on Corps dams and appurtenant structures under ER 1110-2-1806.

b. Legislation. PL 101-614, enacted on 16 November 1990, reauthorized the National Earthquake Hazards Reduction Act of 1977. The purpose of the law is to develop a national program to reduce risks to life and property from future earthquakes. One of the stated objectives is "the development of technologically and economically feasible design and construction methods and procedures to make new and existing structures, in areas of seismic risk, earthquake resistant, giving priority to the development of such methods and procedures for power generating plants, dams, hospitals, schools, public utilities and other lifelines, public safety structures, high occupancy buildings, and other structures which are especially needed in time of disaster." According to PL 101-614, the term "lifeline" means: "public works and utilities, including transportation facilities and infrastructure, oil and gas pipelines, electrical power and communication facilities, and water supply and sewage treatment facilities."

c. Corps projects with lifeline systems in moderate and high risk seismic areas. Moderate, as well as severe or high intensity earthquakes, can cause significant damage to communities and lifeline systems. Moderate earthquakes can be especially devastating when structures are founded on soft clays which amplify earthquake motions or founded on saturated, fine-grained materials which liquefy. The scope of the lifeline evaluation effort, therefore, includes Corps projects located in regions of moderate and high intensity earthquake risk. Regions of seismic risk for this report are described by the Uniform Building Code (UBC) seismic zone map (Figure A-1). For the purpose of this report, zones 2A and 2B represent regions of moderate risk, and zones 3 and 4 represent regions of high seismic risk. Figures A-2 through A-7 show the Corps projects located in regions of moderate and high seismic risk. The regions identified by these figures are:

(1) Northeastern region, including New England and New York (Figure A-2).

(2) Southeastern region, including the central Appalachian seismic region activity and the area near Charleston, South Carolina (Figure A-3).

(3) Central region, which consists of the area between the regions just described and the Rocky Mountains (Figure A-4).

(4) Southwestern region, including New Mexico and Arizona (Figure A-5).

(5) Northwestern region, including Washington, Oregon, Montana, and Idaho (Figure A-6).

(6) California (Figure A-7).

(7) Hydroelectric power plant facilities at risk. The disposition of Corps hydroelectric power plant facilities with respect to the various UBC seismic zones is provided in Table A-1. This table also provides information on the power-producing capacity, the plant location, the river system, and the responsible Corps district and division. The Corps has 8 hydroelectric power plants located in zones of high seismic risk (zones 3 or 4) and 27 plants in zones of moderate seismic risk (zones 2A and 2B).

(8) Guidance and evaluation of major structural features of projects with lifeline systems. Corps of Engineers dams, for the most part, were designed by the traditional seismic coefficient method which does not realistically account for the inertial forces and stresses generated in a dam due to earthquake ground motions. However, in the past 10 years, all Corps dams in seismic zones 2, 3, and 4 were reevaluated for a maximum credible earthquake using the latest state-of-the-art dynamic analysis procedures. The reevaluation effort included all earth-fill, rock-fill, and concrete dams; appurtenant structures; navigation structures; and levees. The Corps has developed a new, state-of-the-art seismic evaluation procedures for intake towers (ETL 1110-2-339). Based on ETL 1110-2-339 procedures, towers designed by the old seismic coefficient method and located in seismic zones 2, 3, and 4 will be reevaluated. The status of all seismic reevaluations will be included in Lifeline Report No. 3. Dams were reevaluated in accordance with ETL 1110-2-301, ER 1110-2-1806, and ETL 1110-2-303.

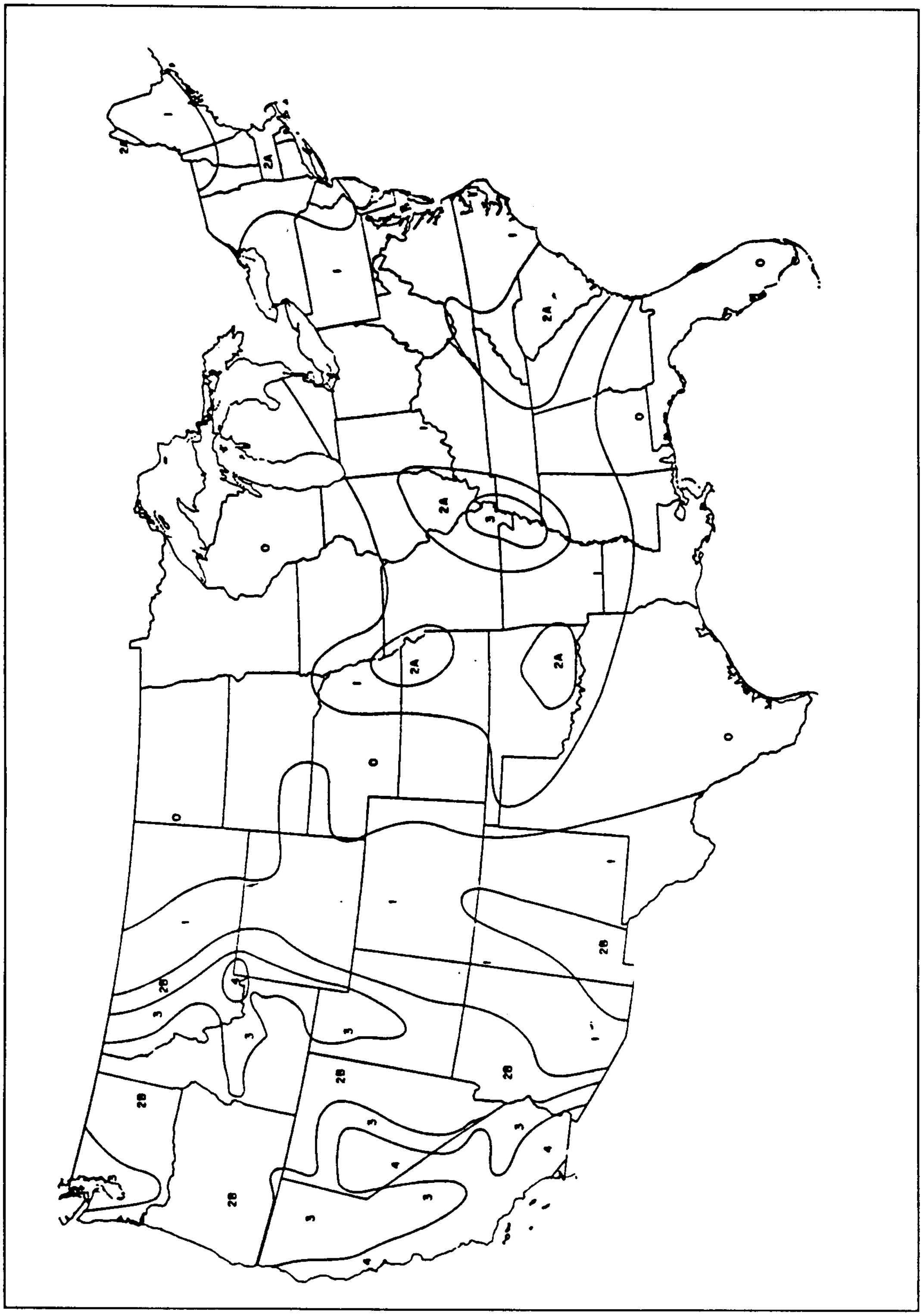

Figure A-1. Seismic zone map of the United States

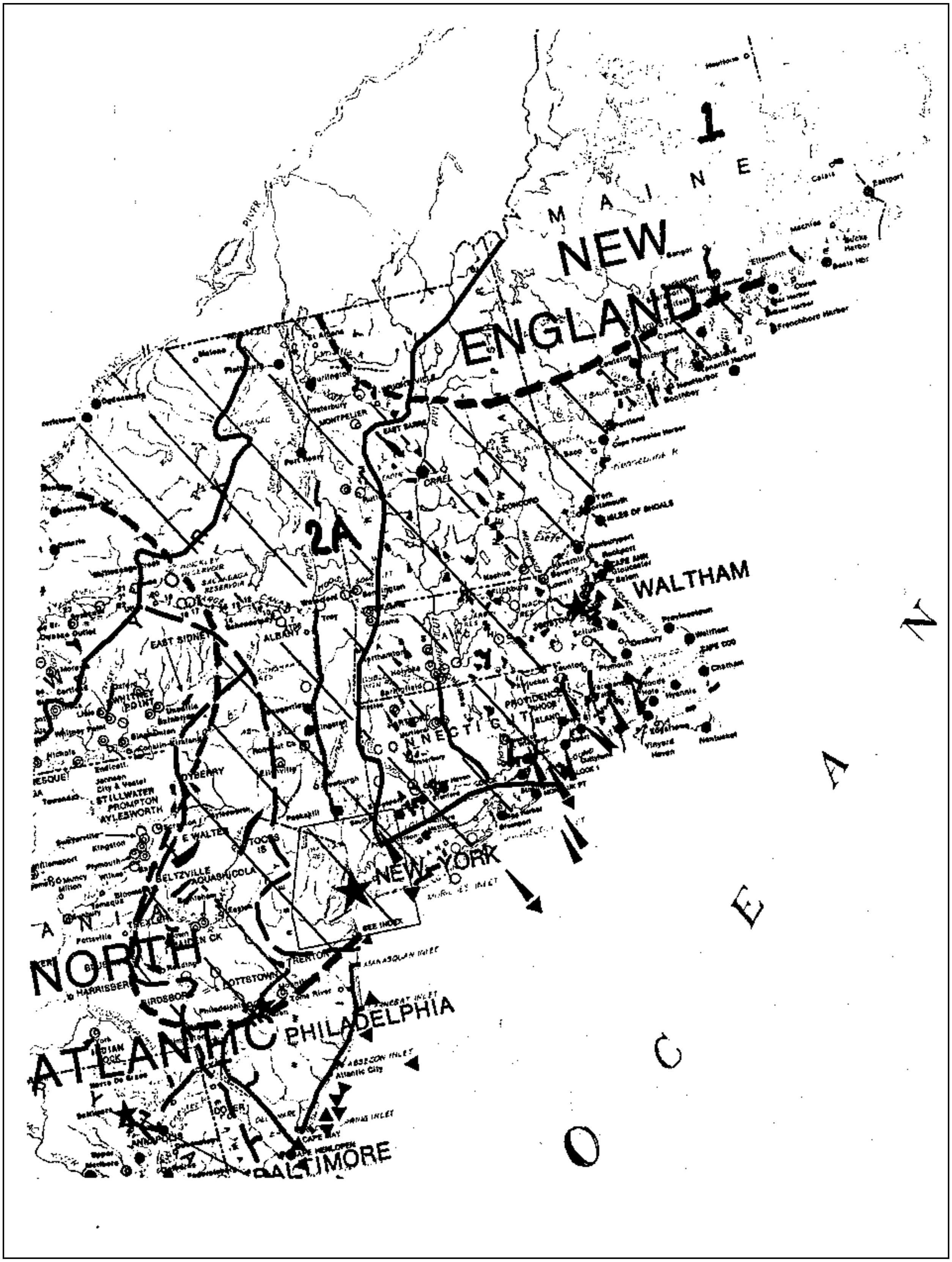

Figure A-2. Corps projects, northeastern region

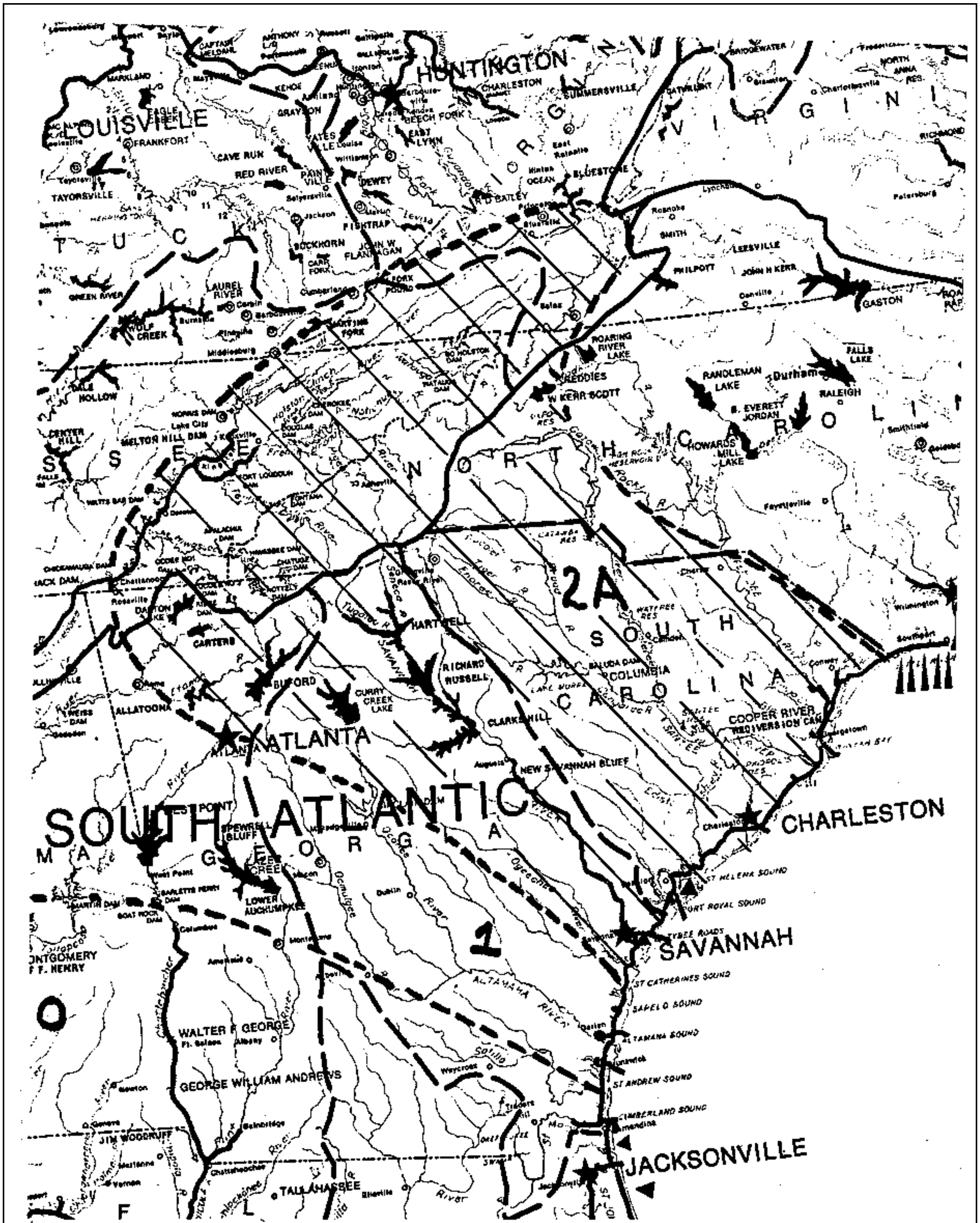

Figure A-3. Corps projects, southeastern region

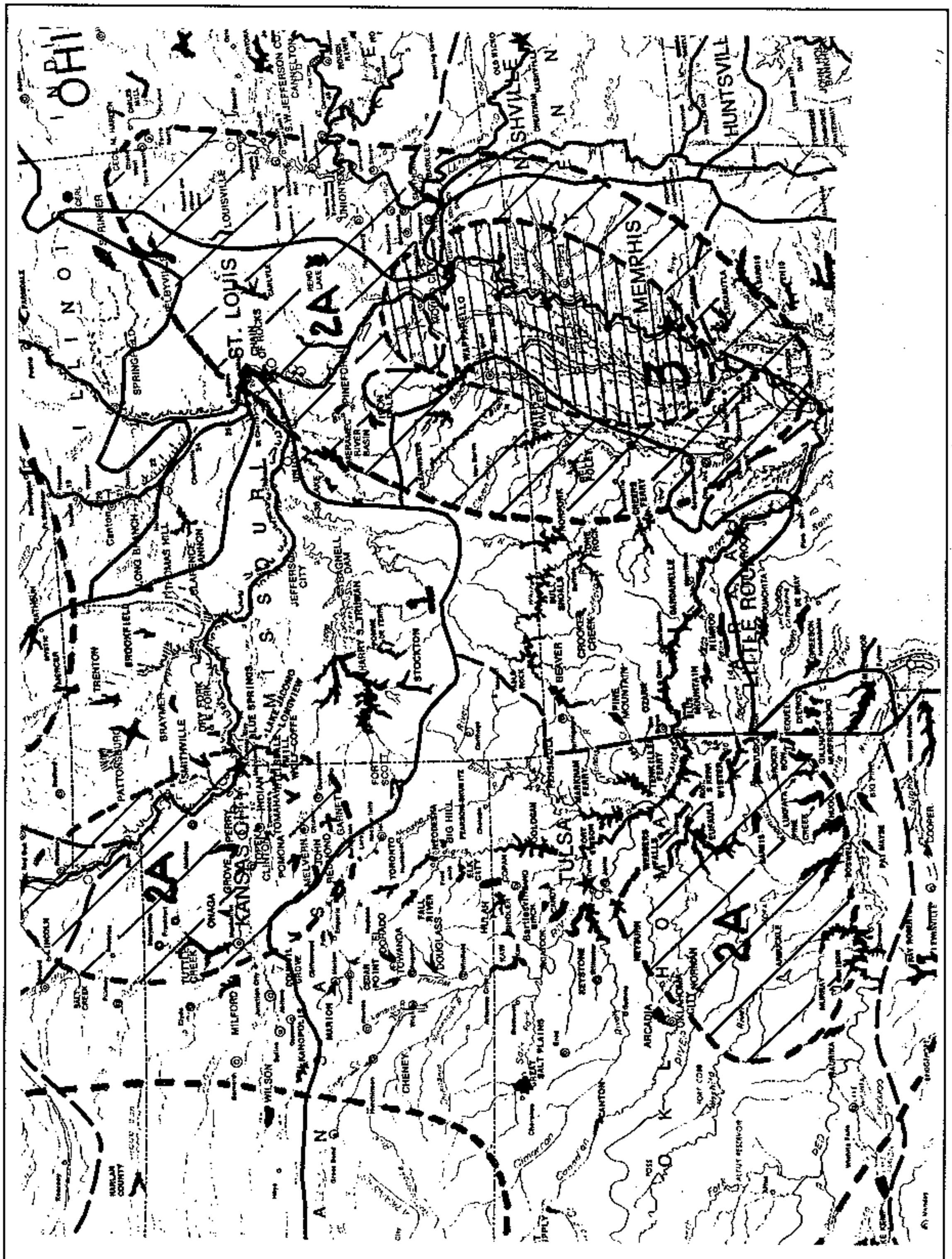

Figure A-4. Corps projects, central region

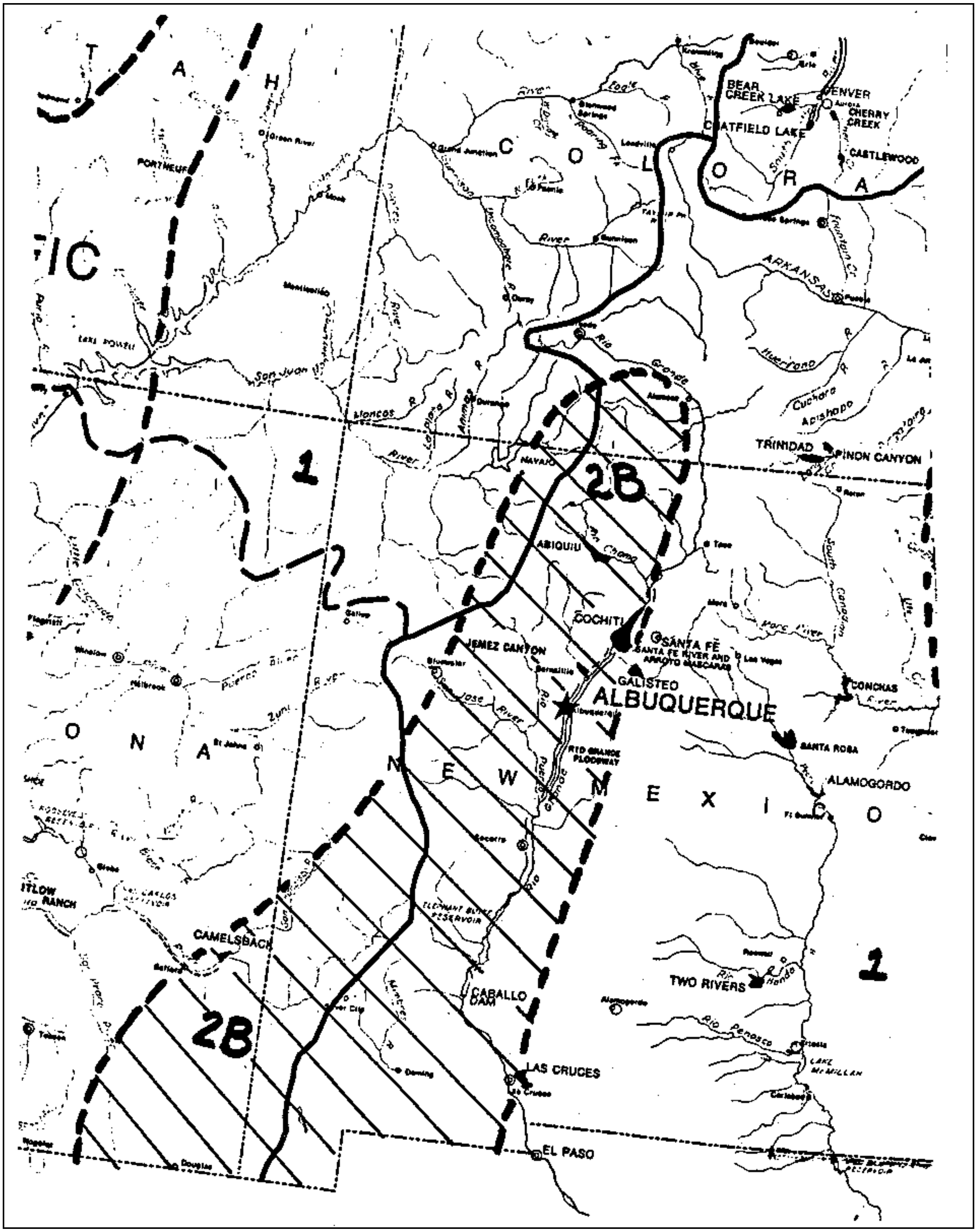

Figure A-5. Corps projects, southwestern region

Figure A-6. Corps projects, northwestern region (reflects zone changes to Oregon and Washington)

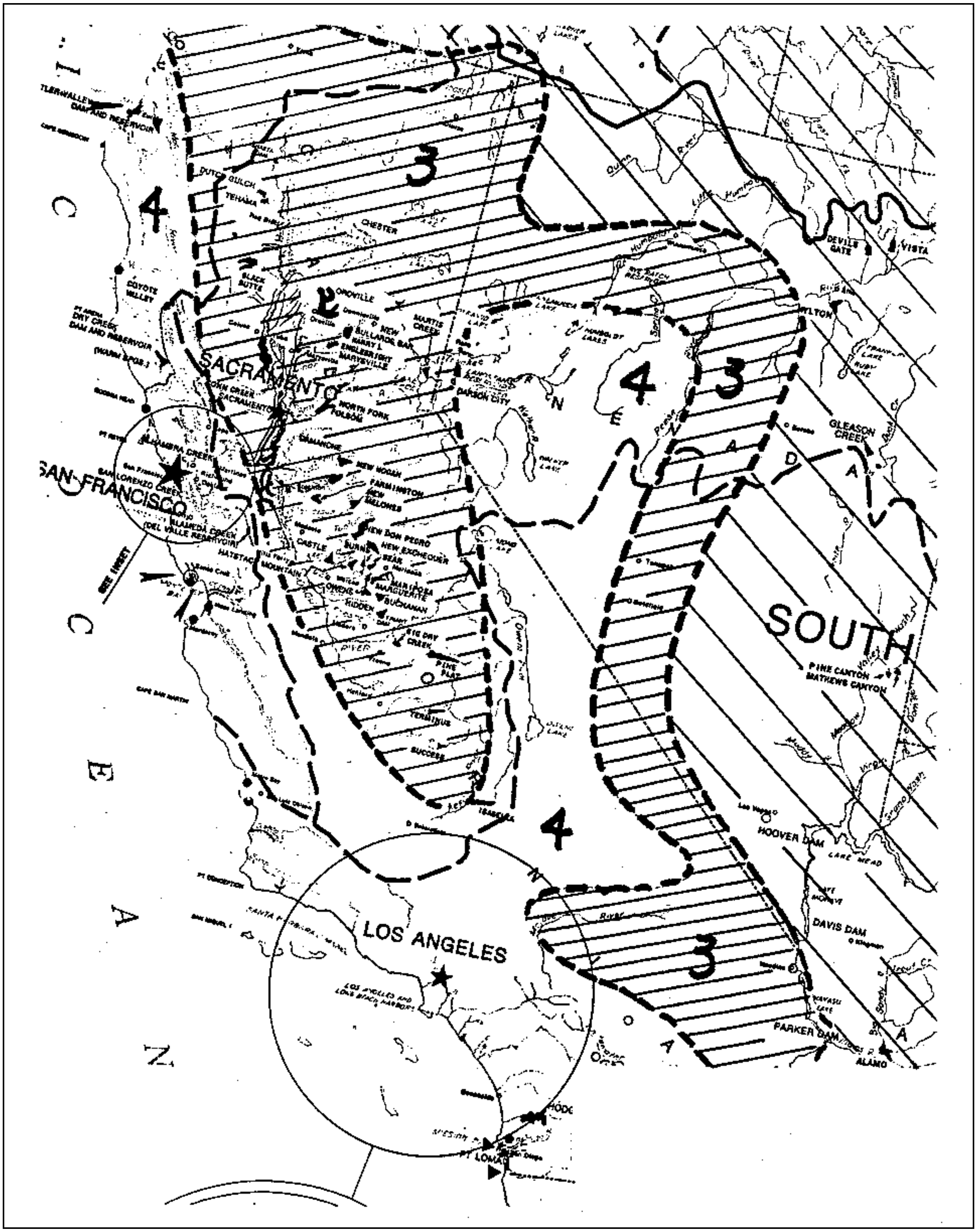

Figure A-7. Corps projects, California

Table A-1
Corps of Engineers Power Plant Facilities

Project	Zone	Corps Division	Corps District	Location	River	Capacity KW
Albeni Falls	2B	North Pacific	Seattle	Idaho	Pend Oreille	42,600
Allatoona	2A	South Atlantic	Mobile	Georgia	Etowah	110,000
Barkley	2A	Ohio River	Nashville	Kentucky and Tennessee	Cumberland	130,000
Beaver	1	Southwestern	Little Rock	Arkansas	White	112,000
Big Bend	0	Missouri River	Omaha	South Dakota	Missouri	468,000
Big Cliff	3	North Pacific	Portland	Oregon	N. Santiam	18,000
Blakely Mt.	1	Lower Mississippi Valley	Vicksburg	Arkansas	Ouachita	75,000
Bonneville	3	North Pacific	Portland	Oregon and Washington	Columbia	1,076,620
Broken Bow	1	Southwestern	Tulsa	Oklahoma	Mt. Fork	100,000
Buford	2A	South Atlantic	Mobile	Georgia	Chattahoochee	86,000
Bull Shoals	1	Southwestern	Little Rock	Arkansas and Missouri	White	340,000
Carters	2A	South Atlantic	Mobile	Georgia	Coosawattee	500,000
Center Hill	1	Ohio River	Nashville	Tennessee	Ganey Fork	135,000
Cheatham	2A	Ohio River	Nashville	Tennessee	Cumberland	36,000
Chief Joseph	2B	North Pacific	Seattle	Washington	Columbia	2,089,000
Clarence Canon	1	Lower Mississippi Valley	St. Louis	Missouri	Salt	58,000
Cordell Hull	1	Ohio River	Nashville	Tennessee	Cumberland	100,000
Cougar	3	North Pacific	Portland	Oregon	McKenzie	25,000
Dale Hollow	1	Ohio River	Nashville	Tennessee	Obey	54,000
Dardanelle	1	Southwestern	Little Rock	Arkansas	Arkansas	124,000
DeGray	1	Lower Mississippi Valley	Vicksburg	Alabama	Caddo	68,000
Denison	1	Southwestern	Tulsa	Oklahoma and Texas	Red	70,000
Detroit	3	North Pacific	Portland	Oregon	N. Santiam	118,000
Dexter	2B	North Pacific	Portland	Oregon	Middle Fork Willamette	15,000
Dworshak	2B	North Pacific	Walla Walla	Idaho	Clearwater	400,000
Eufaula	2A	Southwestern	Tulsa	Oklahoma	Canadian	90,000
Ft. Gibson	1	Southwestern	Tulsa	Oklahoma	Grand	45,000
Ft. Peck #1	0	Missouri River	Omaha	Montana	Missouri	185,300
Ft. Peck #2	0	Missouri River	Omaha	Montana	Missouri	--
Ft. Randall	1	Missouri River	Omaha	South Dakota	Missouri	320,000
Foster	3	North Pacific	Portland	Oregon	S. Santiam	--
Garrison	0	Missouri River	Omaha	North Dakota	Missouri	400,000
Gavins Pt.	1	Missouri River	Omaha	Nebraska and South Dakota	Missouri	100,000
Green Peter	3	North Pacific	Portland	Oregon	S. Santiam	100,000
Greers Ferry	2B	Southwestern	Little Rock	Alabama	Little Red	96,000
Harry S. Truman	1	Missouri River	Kansas City	Missouri	Osage	160,000
Hartwell	2A	South Atlantic	Savannah	Georgia and South Carolina	Savannah	344,000
Hills Creek	2B	North Pacific	Portland	Oregon	Willamette	30,000
Ice Harbor	2B	North Pacific	Walla Walla	Washington	Snake	602,000
J. Strom Thurmon	2A	South Atlantic	Savannah	Georgia and South Carolina	--	--
J. Percy Priest	1	Ohio River	Nashville	Tennessee	Stones	28,000
Jim Woodruff	0	South Atlantic	Mobile	Florida	Apalachicola	30,000
John Day	2B	North Pacific	Portland	Oregon and Washington	Columbia	2,160,000

(Continued)

Table A-1
(Concluded)

Project	Zone	Corps Division	Corps District	Location	River	Capacity KW
John H. Kerr	1	South Atlantic	Wilmington	North Carolina and Virginia	Roanoke	240,000
Jones Bluff	1	South Atlantic	Mobile	Alabama	--	68,000
Keystone	1	Southwestern	Tulsa	Oklahoma	Arkansas	70,000
Laurel	1	Ohio River	Nashville	Kentucky	Laurel	61,000
Libby	2B	North Pacific	Seattle	Montana	Kootenai	525,000
Little Goose	2B	North Pacific	Walla Walla	Washington	Snake	810,000
Look Out Point -Dexter	3	North Pacific	Portland	Oregon	Willamette	135,000
Lost Creek	3	North Pacific	Portland	Oregon	Rogue	49,000
Lower Granite	2B	North Pacific	Walla Walla	Washington	Snake	810,000
L. Monumental	2B	North Pacific	Walla Walla	Washington	Snake	810,000
McNary	2B	North Pacific	Walla Walla	Oregon and Washington	Columbia	980,000
Millers Ferry	0	South Atlantic	Mobile	Alabama	Alabama	75,000
Narrows	1	Lower Mississippi Valley	Vicksburg	Arizona	Little Mo.	25,500
Norfolk	1	Southwestern	Little Rock	Arkansas and Missouri	White	80,550
Oahe	0	Missouri River	Omaha	North Dakota and South Dakota	Missouri	640,000
Old Hickory	1	Ohio River	Nashville	Tennessee	Cumberland	36,000
Ozark	1	Southwestern	Little Rock	Arkansas	Arkansas	100,000
Philpott	2A	South Atlantic	Wilmington	Virginia	Roanoke	14,000
R. B. Russell	2A	South Atlantic	Savannah	Georgia and South Carolina	Savannah	600,000
Rob’t S. Kerr	2A	Southwestern	Tulsa	Oklahoma	Arkansas	110,000
St. Marys	2A	North Central	Detroit	Michigan	St. Marys	18,400
Sam Rayburn	0	Southwestern	Ft. Worth	Texas	Angelina	52,000
St. Stephen	2A	South Atlantic	Charleston	South Carolina	Santee/Cooper	84,000
Stockton	1	Missouri River	Kansas City	Missouri	Sacramento	45,200
Table Rock	1	Southwestern	Little Rock	Arkansas and Missouri	White	200,000
Tenkiller - Ferry	1	Southwestern	Tulsa	Oklahoma	Illinois	9,100
The Dalles	2B	North Pacific	Portland	Oregon and Washington	Columbia	1,806,000
Walt George	0	South Atlantic	Mobile	Georgia and Alabama	Chattahoochee	130,000
Webbers Falls	2A	Southwestern	Tulsa	Oklahoma	Arkansas	60,000
West Point	0	South Atlantic	Mobile	Georgia	Chattahoochee	73,375
Whittney	0	Southwestern	Ft. Worth	Texas	Brazos	30,000
Wolf Creek	1	Ohio River	Nashville	Kentucky	Cumberland	270,000

A-3. Electrical Power and Communications Lifelines

a. General. The original purpose of this report was to assess the vulnerability of hydroelectric power plants to earthquake damage that would impair the plants’ ability to deliver electricity to communities recovering from the devastating effects of a major earthquake. The vulnerability of this lifeline function was assessed by a walk-through of three Corps hydroelectric power plants by a team composed of a recognized lifeline expert, Corps design engineers, and project operations personnel. During the walk-through process, it became evident that the most important electrical power lifeline function was one of providing electrical power onsite in response to emergency conditions. For instance, hydroelectric power plants can be isolated from the power grid when earthquake ground motions trip pressure-sensitive relays in

transformers. These pressure-sensitive relays, provided to protect the transformer from damage due to overheating, often trip due to sloshing of the cooling oil during an earthquake. If this happens, the wicket gates close to prevent generator runaway. All station power must then be provided by sources in the powerhouse. This can include station service units, main units running at speed no load supplying power to plant through reactors and transformers, emergency generators, and batteries. If the emergency power sources are damaged, it is possible the spillway gates or other reservoir control gates cannot be raised. This can jeopardize dam safety if project inflows are sufficient to cause the project to be overtopped before the gates can be put back into service. It can also jeopardize dam safety if embankment dam sections have been damaged by the earthquake and the control gates cannot be operated to effect rapid drawdown of the impoundment. Communications are also dependent on electrical power, and if the communications equipment or its power source is damaged during the earthquake, the project's ability to communicate emergency conditions to upriver plants and others required to take emergency actions would be jeopardized. Therefore, the protection of onsite electrical power and communication is often of much greater importance than that of providing electrical power for postearthquake recovery of communities. Onsite electrical power and communication during and following a major earthquake are critical to Corps flood control projects, navigation lock projects, and water supply projects as well as hydroelectric power plant projects. Therefore, many of the vulnerabilities cited in Appendix B to this report are applicable to all Corps projects.

b. Hydroelectric power plants. Corps hydroelectric power plant projects consist of dam, spillway, and nonoverflow structures; a powerhouse with turbines, generators, transformers, and other electrical equipment; and sometimes a substation with transformers and switching equipment. Navigation locks are often a part of Corps hydroelectric power projects. The dam may be earth-fill, rock-fill, or concrete. The main structural features of power plant structures have been designed for the inertial effects induced by earthquake ground motions and therefore are not the subject of this lifeline report. Turbines and generators are rugged, and damage to these features has not occurred during past earthquakes. This report focuses on the electrical, mechanical, and communications equipment that have in the past been shown to be vulnerable to earthquake ground motion damage. When properly anchored, this equipment performs well. However, unanchored equipment can slide or overturn and experience substantial damage. Switching equipment and ceramics are vulnerable to earthquake damage.

c. Emergency power. Emergency power is an essential feature of all Corps projects. On hydroelectric power plant projects, batteries provide power for control systems and communication equipment. Batteries also provide power to start diesel-powered emergency generators. Emergency generator power is critical to most Corps projects during system outages. These emergency generators provide backup power to operate spillway gates, sump pumps, and outlet works control gates. Unanchored batteries and unanchored or inadequately anchored emergency generators are vulnerable to the damaging effects of earthquakes.

d. Communications equipment. Communications equipment plays an important role in the operation of Corps projects and in the response to emergency conditions occurring on Corps projects. Communication equipment at Corps projects is extremely vulnerable to seismic damage because of its fragile nature and because it is typically unanchored.

A-4. Identifying Earthquake-Vulnerable Electrical and Mechanical Equipment on Corps Projects.

a. General. Evaluating Corps projects for earthquake vulnerability can be accomplished by analytical methods, by onsite walk-through inspections, or a combination of both. Analytical methods are most useful for major structures such as powerhouses, dams, and intake towers where response spectrum analysis or time-history analyses can be used to determine the earthquake forces that are likely to occur during a major earthquake. The vulnerability of mechanical and electrical equipment, however, is best assessed by walk-through inspections which concentrate on features that are known from past earthquakes to be susceptible to earthquake damage. These walk-through inspections should be accomplished by a team of mechanical, electrical, and structural engineers accompanied by someone familiar with the

seismic performance of the various types of equipment on the project, and someone who under stands project systems operation and systems critical to project emergency response.

b. Corps walk-through inspections. Walk-through inspections were performed on two hydro-electric power plant projects as part of the Corps of Engineers Hazard Reduction Program. Professor Anshel J. Schiff, a recognized expert in the seismic performance of electrical power systems, performed the walk-through inspections accompanied by various design engineers and project engineers from the Corps. Professor Schiff is chairman of the Electrical Power and Communications Committee and the Earthquake Investigations Committee of the American Society of Civil Engineers Technical Council on Lifeline Earthquake Engineering, and of the Earthquake Records Committee of the Earthquake Engineering Research Institute. The type of expertise provided by Dr. Schiff ensured that the Corps' effort to assess the seismic vulnerability of its power-generating lifeline systems was in accordance with, and consistent with, standards used by other government agencies and private utilities. As a result of his walk-through inspections, Professor Schiff prepared two reports. The first report provided his findings and recommendations with respect to the specific projects visited. It is evident from his report that the Corps has critical mechanical, electrical, and communications equipment that is vulnerable to earthquake damage. Professor Schiff's second report was structured so it could be used as a guide for evaluating the seismic vulnerabilities of Corps lifeline systems. This second report is attached as Appendix B.

c. Findings. On the projects inspected, much of the mechanical, electrical, and communications equipment was found to be unanchored or inade quately anchored to resist the damaging effects of earthquake ground motions. The equipment described is often critical to continued operation of Corps projects and to emergency response. Particularly vulnerable were batteries required for emergency power, transformers, and communications equipment. The projects inspected are considered typical of all Corps-owned hydropower facilities.

d. Goals and recommendations.

(1) Existing projects. Special walk-through inspections should be conducted on all Corps projects in zones of high or moderate seismic risk. These walk-through inspections should concentrate on vulnerable areas cited in Appendix B. The Corps should take action to provide training for engineers performing these special walk-through inspections, and regulations should be developed which require that the walk-through inspections be conducted in conjunction with periodic inspections of all Corps projects located in seismic zones 2A, 2B, 3, and 4.

(2) New projects. Specifications requiring that all mechanical and electrical equipment be anchored to resist the damaging effects of earthquake ground motion should be included in the contract documents for new projects. Military guide specification CEGS-13080 can be used for this purpose. CEGS-13080 is in the process of being updated to meet current seismic code requirements. As part of the National Earthquake Hazards Reduction Program (NEHRP), national standards are being developed for the seismic protection of lifelines. Any new standards developed under NEHRP should be incorporated into Corps designs when appropriate.

Appendix B: Guidelines for Evaluating the Seismic Vulnerability of Lifelines and Ancillary Systems Required for the Operation of Dams and Mitigation Measures for Reducing Seismic Vulnerability

B-1. Introduction

a. Background.

(1) In response to the 1971 San Francisco earthquake, a Federal initiative addressed seismic vulnerabilities of Federal facilities. This resulted in the Earthquake Hazard Reduction Act of 1977. The interagency Committee for Seismic Safety and Construction was formed in 1978 in response to this act. The Earthquake Hazard Reduction Program was initiated and managed by the Office of Science and Technology Policy, and a letter was issued to Federal agencies suggesting that good seismic practices be used for Federal facilities. In January 1990, Executive Order 12699 was issued which requires new Federal construction to comply with seismic requirements. Under these requirements Federal facilities and facilities that use Federal funds must conform to the seismic requirements of the American National Standards Institute Standards A58, Minimum Design Loads for Buildings and Other Structures. Seismic requirements for lifeline buildings must be established within 3 years after the issue of the Executive Order.

(2) Hydropower provides about 10 percent of the total power-generating capacity in the United States, and the Corps of Engineers supplies about 30 percent of this. The Corps is the largest producer of hydroelectricity and operates 70 projects housing 344 turbine generators. Many of these facilities are located in moderate to high seismic zones.

b. Scope. The procedures outlined herein are for the evaluation of lifelines and operating systems that may impact the seismic performance of dams and ancillary systems. The procedures do not include the evaluation of structural aspects of the dam or other structural elements or systems. The outline is based on a 2-day review of two facilities.

c. Approach to vulnerability evaluation and mitigation. The approach to the evaluation of facility vulnerability has been based primarily on the seismic performance of similar equipment at power and industrial facilities during earthquakes, both in the United States and foreign. In the past, there has been a strong dependance on informed engineering judgment rather than detailed analysis and formal calculation.

d. Organization. This outline for evaluating the vulnerability of dam lifelines and ancillary systems is divided into five parts. The first part reviews the general effects of earthquakes and the impact on lifelines and dam ancillary systems. The second part identifies systems critical to dam operation and the emergency response after a damaging earthquake. The third part describes the vulnerabilities and measures to improve the seismic response of those systems needed for the protection and safe shutdown of the dam after an earthquake. The fourth part describes the vulnerabilities and measures to improve the seismic response of those systems needed for the continued operation of the dam. The fifth part discusses issues related to disaster response plans and their exercise. It should be noted that when mitigation measures are discussed in one section of the report, they will not be repeated in subsequent sections when similar equipment is discussed.

B-2. Earthquakes and Their Impact on Lifelines and Dam Ancillary Facilities

Knowledge of the effects of earthquakes and their impact on lifelines has been gained from observing earthquakes that have occurred in many parts of the world. Several phenomena are associated with earthquakes: ground vibrations, soil liquefaction, subsidence, ground faulting, landslides, and tsunamis. The significance that any phenomenon has for a particular region depends on the characteristics of the region and the facilities in the area. Each of the following sections will discuss one of the phenomena associated with earthquakes and give an example of its impact on lifelines.

a. Ground vibration.

(1) When an earthquake occurs, seismic energy radiates away from the causal fault in the form of

ground vibrations. The vibration of the ground will induce vibration in the structures and equipment resting on the ground. In general, the severity of the ground shaking decreases as the distance from the source increases; however, local soil conditions can significantly change the character of the ground motion and increase its damaging effects. As the depth and softness of the soil at a site increase, the low frequency content of the ground motion is amplified and the high frequency content tends to be attenuated. Ground vibration levels may be amplified by soil conditions by a factor of three or more. Equipment supported in structures may experience an additional amplification due to the response of the structure. Soil and structure amplification tend to attenuate high frequencies and amplify lower frequencies, with the boundary between high and low frequencies depending on the characteristic frequency of the soils and the lower natural frequencies of the structure.

(2) Earthquake excitations can be characterized by the amplitude of the shaking, its frequency content, and its duration. The frequency content of earthquake ground motions often coincides with lower natural frequencies of a significant portion of lifeline facilities and equipment. The effect of earthquake-induced vibration is the major cause of lifeline equipment damage.

(3) The response of ground-mounted structures and equipment is not only determined by the amplitude of the ground motion but also by the degree to which the frequency content of the ground motion matches the natural frequencies of the items being excited. Likewise, the response of equipment mounted in structures is also influenced by the match between the frequency content of their input and their natural frequencies. Thus, equipment mounted in structures may experience a dynamic response much larger than the ground motion.

(4) Vibration-induced sloshing of oil in transformers and motion of transformers frequently cause sudden pressure relays to trip, causing circuit breakers to isolate transformers. As a result, in moderate and strong earthquakes, busses are often de-energized so that there is a loss of offsite power. Massive objects, such as power transformers, require substantial anchorage to prevent movement relative to support structures when ground motions are imposed, as in earthquakes. The transformer shown in Figure B-1 moved over 3 ft in the 1971 San Fernando earthquake (Richter magnitude 6.4). The motion of the transformer can cause bushings and surge arrestors to be damaged, particularly if rigid bus is used. Control cables can also be damaged.

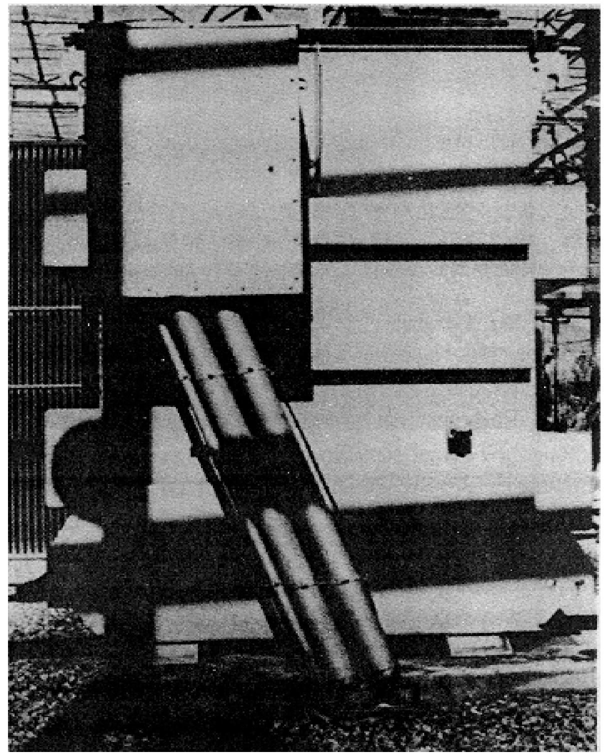

Figure B-1. Motion of unanchored transformer

b. Soil liquefaction.

(1) Under certain conditions, when saturated soils experience vibrations, shear strength decreases and soil liquefaction can occur. Liquefied soil has been observed to flow on 1 percent grades. Surface-supported structures have settled several feet below grade, and buried tanks have floated to the surface. Lateral spreading associated with liquefaction can cause large horizontal motions, often several feet. Even when a rail-mounted transformer (Figure B-2) is secured by chocks, the chocks can slip, or the transformer can tip over damaging bushings, radiators, bus work, and internal parts and connections. In Figure B-3, the transformer pushed the chock off of the end of the rail and allowed the transformer to fall from its pedestal.

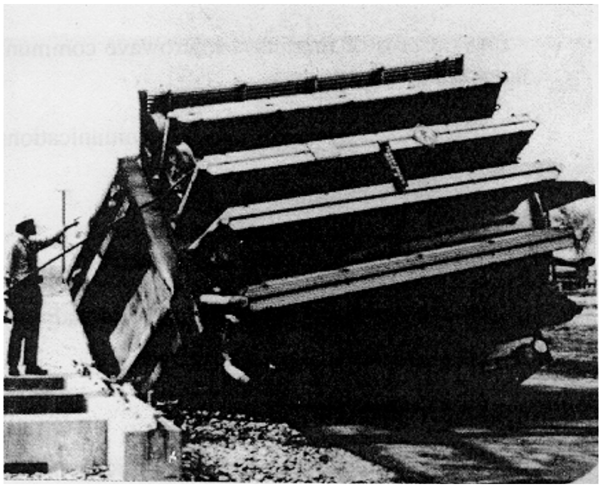

Figure B-2. Failure of a rail-mounted transformer

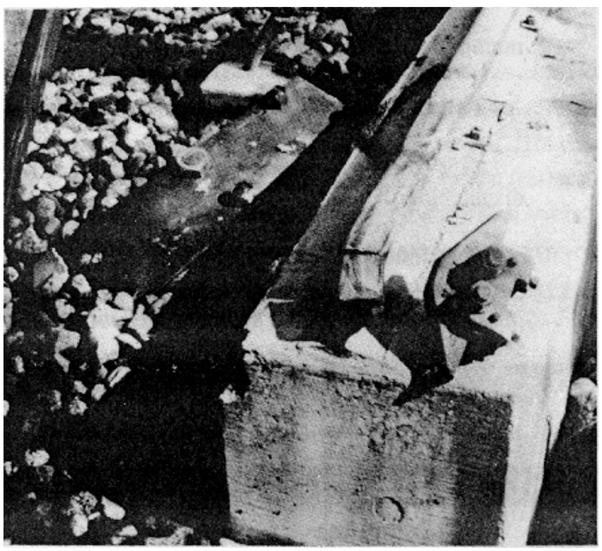

Figure B-3. Chock used to restrain rail-mounted transformer

(2) Factors contributing to liquefaction are the amplitude and duration of shaking, a high water table, low soil density, and the granular character of the soil. These conditions are common adjacent to rivers and lakes.

(3) Buried pipelines are frequently damaged due to liquefaction-induced soil deformations. The bell and spigot connections commonly used for water pipe frequently pull apart, disrupting service.

c. Subsidence. Under certain conditions, an earthquake may cause extensive settling and slumping of the ground. This can cause severe damage to buried utilities such as water, gas, and oil lines, particularly where they enter a structure, due to subsidence of soil around the foundation of the structure. It is very common for soil behind a bridge abutment to settle, creating a large vertical offset in the road, and disrupting or blocking traffic.

d. Ground faulting. Faults are fracture planes in the ground where there is relative motion between the rock on each side of the fracture. In areas with multiple, closely spaced fractures, the area is referred to as a fault zone. Anything spanning the fault, such as buried pipe, cable, or a structure, can experience severe deformations and loads. Depending on the earthquake, the offset across a fault can be both horizontal and/or vertical. Offsets across faults can be quite large; the maximum observed in the Landers earthquake was 23 ft.

e. Earthquake-induced landslides.

(1) There are many regions in which earthquake-induced shaking triggers landslides. The topography and soil conditions are the primary controlling variables, but should the earthquake occur during a rainy season when soils are saturated, the situation can be aggravated. Slides can cause excessive deformations in the ground, and the motion of the soil may sweep away structures and equipment in its path. Pipelines crossing the landslide or embedded in the moving soil are usually severely damaged.

(2) Landslides that fall into bodies of water can also induce large water waves. In the 1964 Prince William Sound earthquake, a massive landslide caused water to rise 1,500 ft above the surface of the sound when the water wave impinged on the opposite side of the sound.

f. Earthquake-induced water waves - tsunamis. Earthquakes occurring offshore that have vertical components can generate large, long period waves, called tsunamis. Typically, these waves are barely perceptible in deep water; however, they can generate massive waves when encountering a land mass with certain types of shoreline topographies.

B-3. Identification of Systems Critical to Operation and to Emergency Response after a Damaging Earthquake

a. The mix, configuration, and operation of the numerous systems necessary to operate and control dam facilities are unique to each dam. It will be necessary for a systems engineer intimately familiar with a facility to determine which systems can adversely impact safe shutdown or operation. It is important that this evaluation be made with the understanding that operation of any one system must be evaluated when several other systems (or any mix of systems) may be inoperative or malfunctioning at the same time. This is not an easy task because of the large number of systems involved, and the fact that interactions and interdependencies may not be well understood. Because of the rarity of dams being subjected to damaging earthquakes, there is little experience of how a dam's system will respond. Also, because of their rarity, emergency response planning seldom takes into account the special problems introduced by earthquakes.

b. In evaluating the response of a dam to an earthquake and identifying the systems that might be needed to respond, it should be assumed that the dam will be separated from the power grid because of problems with the power transmission network. Special consideration should be given to the interaction of dam facilities. Some interactions may not be well understood or may be hidden. A common example is power to critical components of a system that were added or modified after the initial construction in which the item was inadvertently connected to regular power circuits rather than to circuits provided with emergency power. Another example would be waterlines outside of the dam that have branches that are not well documented. A failure in one of these lines may depressurize and drain the system.

c. Several of the systems that may be critical for the safe shutdown of the facility or its continued operation are listed below:

(1) Emergency batteries and emergency power for monitoring, control, and other systems.

(2) Spillway control systems.

(3) Wicket gate governor systems.

(4) Radio system for onsite communications.

(5) Corps of Engineers microwave communications system.

(6) Radio system for offsite communications.

(7) Sump pumps.

(8) Normal house power.

(9) Power switchyard equipment including stepup transformers.

(10) General equipment.

(11) Generator thrust bearing lubrication system.

(12) Generator bearing lubrication oil cooling system.

(13) Water used for air conditioning needed to maintain computers or communication systems.

(14) Computer systems.

(15) Communications system for power network dispatching.

(16) Internal telephone system.

(17) External public switched network telephone system.

(18) Miscellaneous systems.

(a) Elevators.

(b) Critical access roads.

(c) Suspended ceilings in control rooms.

(d) Relays.

d. The seismic vulnerability and mitigation measures for each of the above systems will be discussed in one of the two following sections. The next section discusses systems required for dam protection or the safe shutdown of dam operations. The subsequent section describes systems needed for continued operation of the dam. For a particular facility some of these systems may be shifted between these two sections. For the configuration of some facilities, there may be other systems that are not listed here that should be considered for the

protection or operation of the dam. Also, the role of some of these systems may be different than characterized here.

B-4. Systems Needed for the Protection and Safe Shutdown of Dams

The malfunction of any of the systems listed below may cause severe damage to or interfere with the safe shutdown of the system. In some cases, additional systems may be needed for the protection or safe shutdown of the dam, depending on how the dam's systems are configured. Some of the seismic vulnerabilities of these systems will be discussed along with mitigation measures.

a. Emergency batteries and emergency power for monitoring, control, and other systems.

(1) The loss of power for system monitoring and control can have disastrous consequences. In the event of a significant earthquake, it is likely that there will be a loss of power grid connections, even if there are no problems at the damsite itself. Dams have several sources of house power, including power from the main turbines, house power turbines, or a separate external line from the power grid. Emergency sources of power may include an engine generator and one or more sets of emergency batteries (generally, each set for a specific purpose) with chargers and inverters. A given site may not have all of these power sources available.

(2) Emergency batteries are a key element in power system facilities. Failure of the batteries or ancillary equipment may cause a short circuit so that station and emergency power may be disrupted, which may cause a total loss of system control. Emergency batteries should be secured. Because of the weight of batteries, from 30 to 200 lb per cell, substantial racks that are well anchored must be provided. Battery restraints should prevent batteries from falling off of the sides and end of the rack. Ideally, the lateral restraint should be positioned about the center of gravity of the cells and should fit close to the battery case. Stiff spacers should also be placed between cells to prevent cell cases from impacting each other and from longitudinal motions loading battery cell terminals. Dense polyurethane foam is often used.

(3) The battery restraints in Figure B-4 are anchored with two 3/8-in. bolts at each end. Even if the anchorage does not fail, motion in the transverse direction would cause significant deformation in the long, end-supported lateral rail restraint. This would allow the batteries to impact the opposite rail when the motion reverses direction. Impacting can crack battery cases causing an acid spill or loss of power. Rail supports should be provided every three to four cells to ensure both strength and stiffness of the restraints.

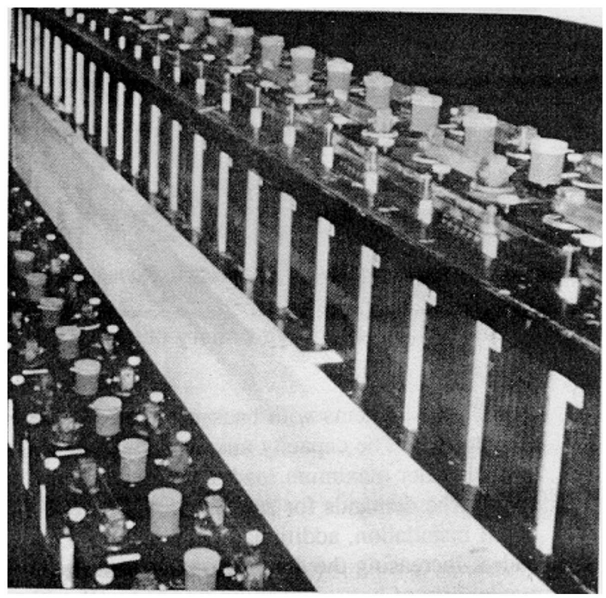

Figure B-4. Inadequate battery restraints

(4) When batteries are unanchored, the need for anchorage is obvious. It is important to check situations where restraints and anchorage are present, but are inadequate. More stringent design criteria for batteries, as compared with other parts of the system, should be considered because of their importance to the operation and safety of the facility, and the fact that the incremental cost of conservative design is small.

(5) Inverters and chargers should be well anchored, and the load path to the base for heavy internal components, such as transformers, should be checked. Units have been found in which internal support of the transformers was inadequate or details of the base anchorage lacked strength or stiffness.

(6) Figure B-5 shows an unanchored charger. Anchorage provisions are sometimes provided but not fully executed. The strength and stiffness of the fabricated channel used to form the anchorage should also be checked.

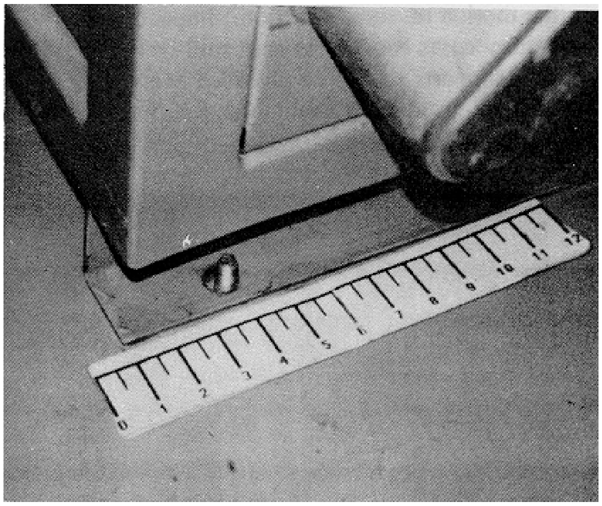

Figure B-5. Unanchored battery charger

(7) All systems with back-up batteries should be inventoried. The capacity and operating life of each system under maximum load should be checked against the demands for safe shutdown. After the initial installation, additional equipment is sometimes added, increasing the demand on the batteries. The availability of battery back-up power to all critical systems should be verified. Redundant back-up batteries or a means for cross-connecting emergency batteries should be considered for vital control and communications facilities.

(8) Engine generators are another critical element for system protection and safe shutdown. They are often vibration-isolated to prevent engine vibration from entering the support structure.

(9) The vibration isolators are often very vulnerable to earthquake damage if they are made of cast iron components and are not designed to withstand impact loads imposed by earthquake-induced base motions. Failure of the vibration isolation system can cause large displacements of the engine generator, thereby damaging its utilities, such as fuel line, electrical connection, control cable connections, and cooling system connections. Generally, engine generators need not be vibration isolated.

(10) A damaged vibration isolation system is shown in Figure B-6. A cast iron retainer around the spring failed due to impacts from lateral earthquake-induced motions. In this example, the equipment shifted about 4 in. to the left. Snubbers restraining lateral motion should have been added to the system.

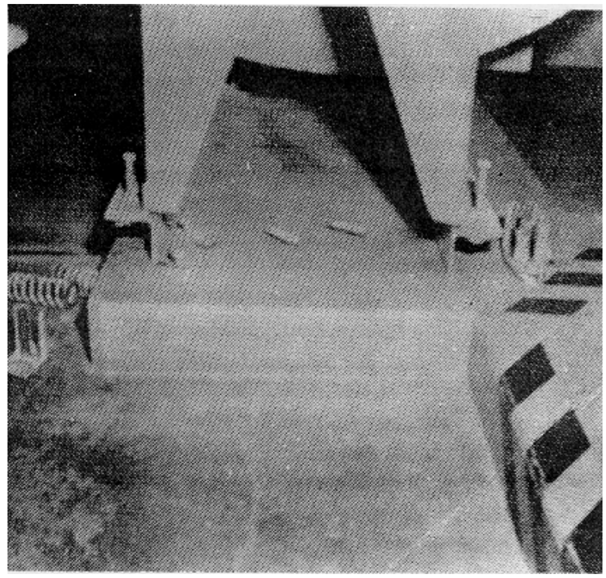

Figure B-6. Damaged vibration isolation system

(11) Figure B-7 shows a type of vibration isolator that frequently fails. The members enclosing the spring are made of cast iron, and there are no restraints to limit the motion of the unit if the isolators fail. Failure of the vibration isolators can cause the engine generator to move more than a foot. This may cause the failure of fuel, water, power, and control lines.

(12) Simple restraints fashioned from a short section of heavy angle iron bolted to the floor will allow the vibration isolation system to operate as designed (Figure B-8). Snubbers limit the lateral movement of the engine generator if the isolators fail. Rubber bumpers will reduce the effect of impacts, although engine generators are generally quite rugged.

(13) The batteries used to start the engine and the daytank (small fuel tank near the engine) must be securely restrained. The integrity of the fuel line connecting the main fuel tank to the daytank should be evaluated. The engine generator control panel should be well anchored.

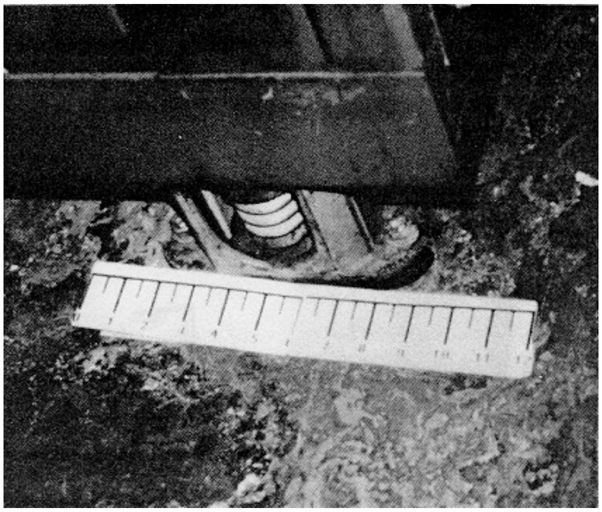

Figure B-7. Vulnerable engine generator vibration isolation system

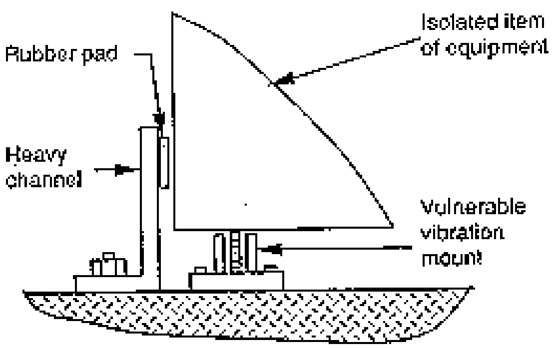

Figure B-8. Simple snubbers can limit generator movement

(14) The batteries used to start emergency generators (Figure B-9) are usually relatively small and few in number. Simple restraints can be fabricated to prevent their being damaged. In some cases it may be easier to secure batteries to a nearby wall, than to modify the rack.

(15) Hidden dependencies, such as power to operate a pump to carry fuel from the main tank to the daytank, or an external water source needed for engine cooling, should be evaluated. Diesel fuel stored for emergency generators can turn "sour" in about 5 years. That is, lumps develop in the fuel. These can clog fuel filters or injectors. Growth inhibitors should be added to the fuel, and the deterioration of the quality of the fuel should be checked.

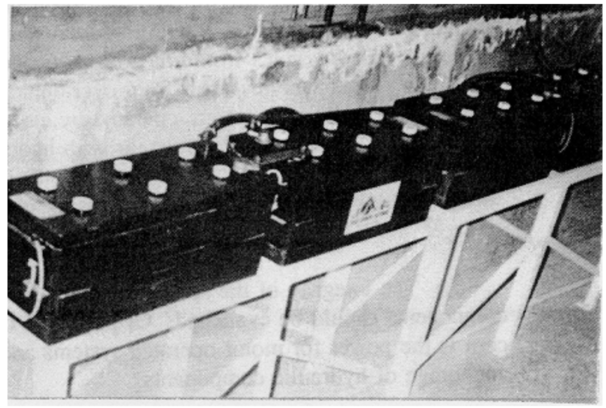

Figure B-9. An emergency generator with unsecured batteries

(16) If possible, it is desirable to periodically check the engine generator under full load, although this is typically difficult to do. It is also desirable to check the unit at least once for an extended period under full load when the ambient temperature is high to ensure the adequacy of the cooling system. The testing of automatic starting units should be done so as to exercise all elements as they would normally be operated after a loss of power. For example, if the loss of power to a relay causes contacts on the relay to close, starting the generator, the testing procedure should place a switch to open the circuit to the relay coil and not short out the relay contacts. Periodically, say every few years, the capacity of the generator should be checked against the load, as equipment tends to be added to emergency power circuits.

(17) Procedures should be established and posted near the unit for manually starting the engine generator. This procedure should include instructions for the positioning of all controls, which in turn should be labeled. Controls to be considered include cooling water shutoff valves, engine over-temperature interlock, load transfer sequence switches, over-current circuit breakers, dampers for shutting the system down, etc. It is desirable to provide external power hookup terminals at a location a mobile generator can be positioned.

b. Spillway control system.

(1) In a moderate to severe earthquake, it is possible that all power will be lost at a project. In that case, the water flowing through the turbines will be shut off automatically. At many hydropower plants the spillway gates would have to be opened quickly to prevent the reservoir from overtopping the dam. These spillway gates are operated by electrical, motor-driven cables, gantry cranes, or with hydraulic systems. Engine-driven backup power systems should be provided to operate this system during an emergency.

(2) The integrity of the spillway control system components should be evaluated. Of particular concern is the power for motor-operated systems and anchorage of hydraulic components.

(3) The response time for opening the spillway gates should be checked to ensure that it is adequate if all turbines are shut down.

c. Wicket gate governor systems.

(1) The wicket gates are usually operated by a hydraulic governor system. The governor system consists of a pump or pumps and oil sump, an oil tank covered by high pressure air, hydraulic valves, hydraulic actuators, piping connecting system components, and electronic monitoring devices and control circuits. When fully charged, the system can operate the wicket gates about five times without using the pump. The various elements of the control system and the elements of the hydraulic system should be evaluated.

(2) In general, piping systems are seismically rugged and perform well if long, unsupported pipe runs are avoided. Pipe failures are usually associated with the relative motion between pipe anchor points, for example, a pipe anchored to two different structures, or a pipe connected to a heavy, unanchored object, such as a tank (Figures B-10 and B-11). Oil tanks, which are often found in these systems, must be securely anchored. When the incoming pipes are rigid, it is desirable to design the piping system so that tank piping connections are flexible to accommodate moderate tank movements. Another common piping failure is associated with a small diameter pipe that is relatively inflexible coming off of a large pipe that is flexible.

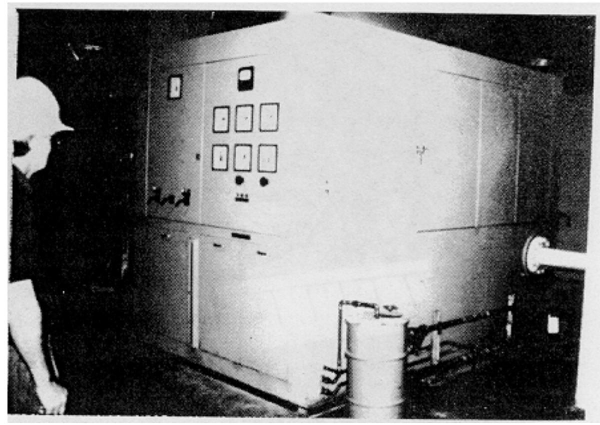

Figure B-10. An unanchored heavy item of equipment can cause a pipe failure. An unanchored pump and sump used to operate the wicket gates can cause a pipe or pipe flange failure. Loss of pressure would deactivate the hydraulic wicket gate system

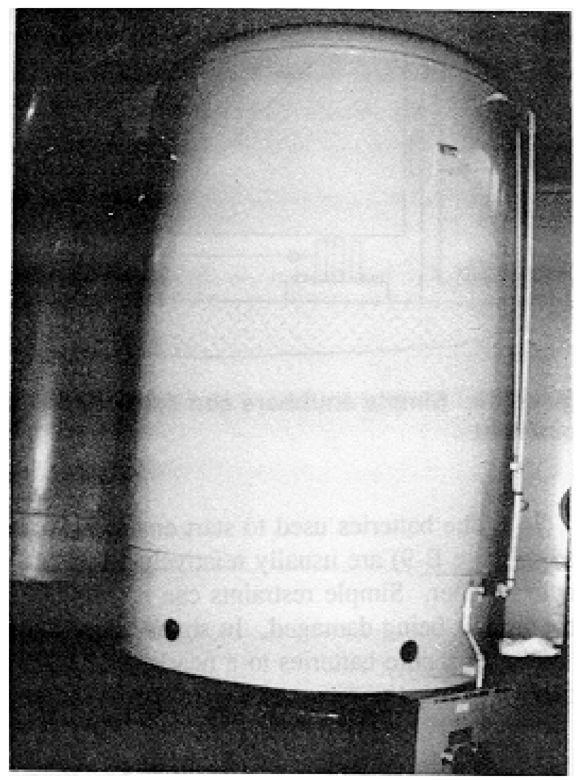

Figure B-11. An unanchored tank in the wicket gate hydraulic system. The unanchored tank in the wicket gate hydraulic system would cause the failure of the main piping system if the tank tips over, or break a smaller pipe if it moves slightly

d. Radio system for onsite communications.

(1) The operation of the radio system for dispatching maintenance crews to evaluate and repair systems is vital, particularly for a facility as large as a dam.

(2) Base station equipment and other communication racks should be anchored and provided with emergency power (Figure B-12). Circuit packs (circuit boards) in racks should be positively secured in their card cages. A means for getting voice signals into the base station should be assured. The microphone used by the chief operator is often unanchored so that it could fall, be damaged, or have its lead wires pulled out in an earthquake. Repeaters are usually necessary to reach all parts of the site, and they should be anchored and provided with emergency power. Ideally, repeaters within the dam should be connected to the emergency power system. If batteries are used for back-up power for repeaters, a means for replenishing them should be provided; that is, back-up batteries at the appropriate voltage and capable of being connected to the system should be available and charged. Many hand-held radios use custom battery packs so that generally available conventional batteries cannot be used. If special batteries are used in hand-held radios, there should be a set of back-up batteries that are on chargers connected to the emergency power supply. The base station and repeaters should be located so that they are protected from water should there be a pipe break or leaking from above the communications room.

(3) Unanchored radio equipment can tip over causing damage to internal components or damaging cables. Radio equipment is frequently small and is not encumbered by numerous cable connections so that it may be easy to move the equipment to install expansion anchors below the cabinet. Equipment can also be anchored to structural walls, or if the equipment is light-weight, it can be anchored to a nonstructural wall if care is used to distribute the load to structural members within the wall.

(4) The retrofit of anchorage to installed equipment can present special problems as it may be difficult to gain access to the base of the equipment to drill and install anchor bolts or move the equipment (Figure B-13). Often, simple angle iron brackets can be bolted to the floor adjacent to the ends of the inadequately anchored cabinet and then welded or bolted to the cabinet. The load path between the cabinet and the new anchor should be checked.

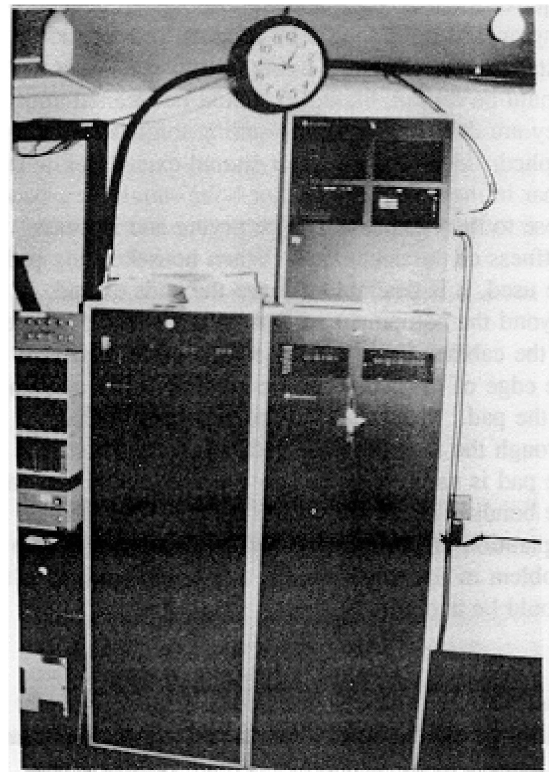

Figure B-12. Radio equipment cabinets must be anchored

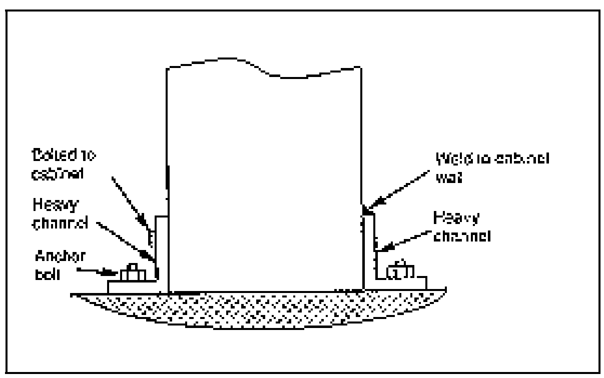

Figure B-13. Retrofitted anchorage to cabinet that is difficult to move

(5) Adjacent cabinets should be bolted together to prevent banging and to provide redundancy should a base anchor be installed incorrectly or fail. This method must be used with caution for long, multi-bay lines of equipment. The retrofit of anchorage usually requires the use of expansion anchors. In general, long anchor bolts should be used as well as good installation practices. That is, proper size holes should be drilled, the holes should be cleaned after they are drilled, and proper setting torques should be applied. Ideally, the anchor should extend below the rebar in the slab. The anchor bolts should be placed close to the cabinet to reduce prying and increase stiffness of the anchorage. When housekeeping pads are used, it is desirable to have the pads extend beyond the equipment so that bolts through the base of the cabinet frame (which should be located near the edge of the cabinet) have adequate edge clearance to the pad. Ideally, anchor bolts should extend through the housekeeping pad into the floor slab as the pad is usually poured after the slab is poured and the bonding of the pad to the floor is questionable. Separation of the pad from the floor has not been a problem in past earthquakes. Lead-type anchor bolts should be avoided.

(6) Typically, communications equipment is installed in tall frames that have a narrow footprint so that large overturning moments and prying loads can be applied to the anchorage (Figure B-14). Even when provided with a strong anchorage, these frames tend to be very flexible, so that large amplification from earthquake-induced motion can be expected. In a few cases, cable connections have been pulled loose due to the motion of the equipment frame. Because of the flexibility of these frames, it is desirable to have them braced at the top to a structural wall by means of a brace or a cable tray that has structural integrity. This will reduce the motion of the frame and the loads applied to the anchorage. Frequently, frames of different heights are placed next to each other so that it is difficult to attach each frame to the overhead bracing system. Bolting adjacent frames together simplifies the bracing and adds redundancy (Figure B-15).

(7) Another problem that has frequently been observed in communication equipment is that circuit packs (circuit boards) vibrate loose (Figure B-16). Typically, card cages do not have doors, and circuit packs may be held only by the friction of the connector where they plug into the back plane of the card cage. Locking type card pullers are desirable, but

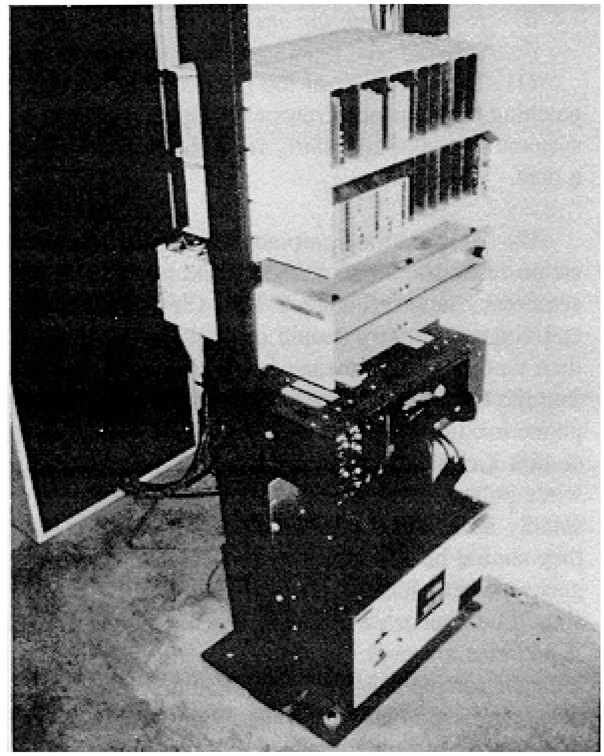

Figure B-14. Base anchorage of a typical communication frame

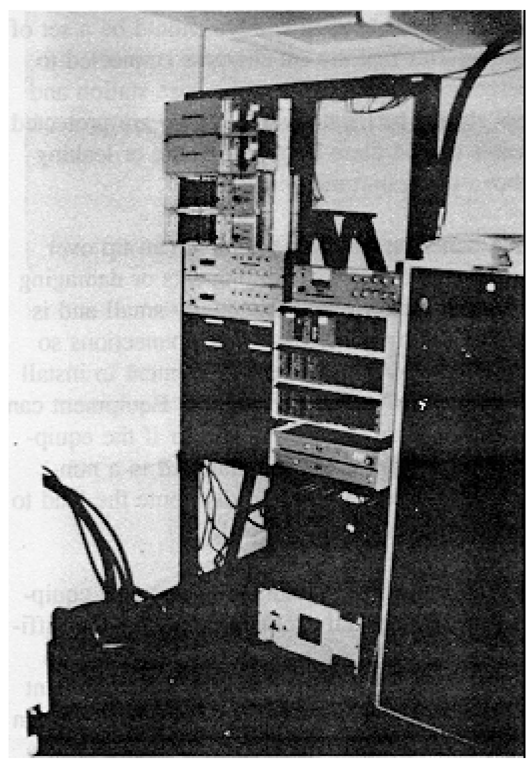

Figure B-15. Bolt adjacent racks together

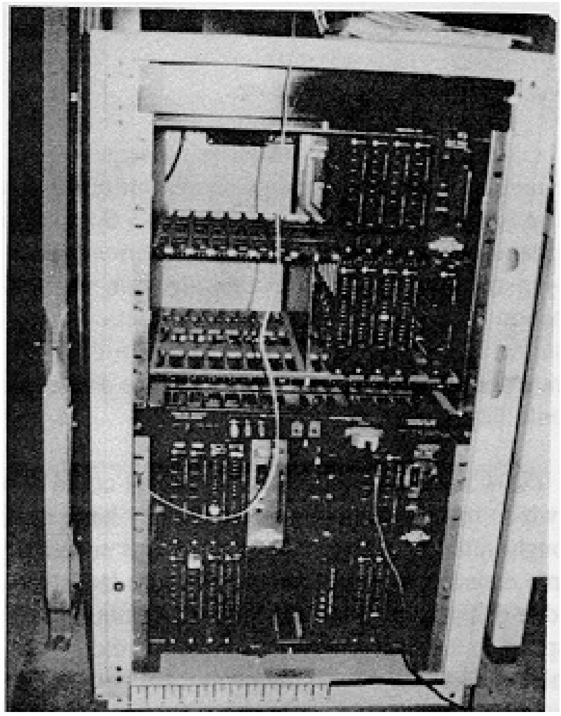

Figure B-16. Communication equipment with unrestrained circuit boards

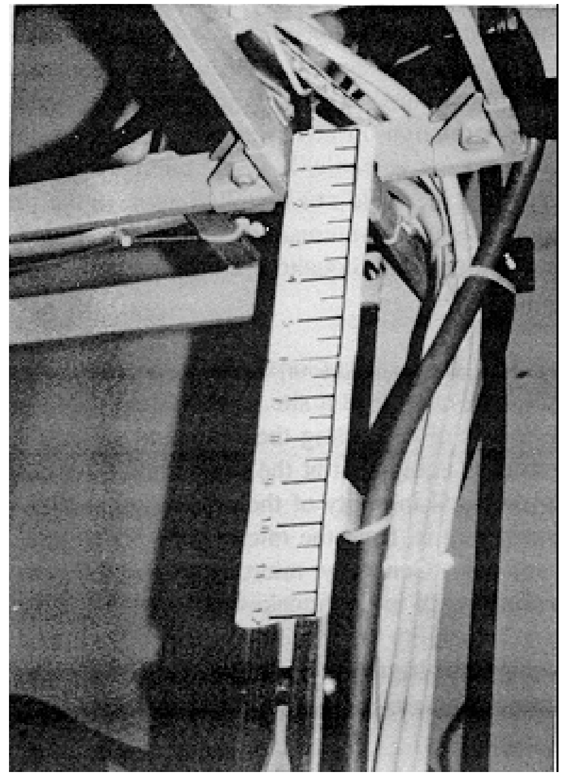

Figure B-17. Communication cable tray

typically not incorporated in older equipment. A rod placed across the front of the card cage through holes drilled in the ends of the cage can serve as a retaining bar to keep circuit packs from vibrating loose. A potential difficulty with this method of protection is that in the course of normal operations, restraining rods are removed and then not replaced.

(8) Cable trays for communications systems such as telephone, radio, and microwave systems are typically different from those used for power or control cables. In many cases the cable trays provide bracing at the top of communication equipment frames so that their structural integrity is important. A common design detail of communication cable trays is the use of friction clips to connect cable tray sections (Figure B-17). Thus, structurally, components do not have positive connections, even though they may be used to brace equipment frames. A simple strap bolted to adjacent trays would provide a positive connection. If the tray is not used as frame bracing, the addition of positive connections may not be warranted as the decoupling of a cable tray section is unlikely to damage the cables. Cable trays using top brace equipment should be adequately anchored to walls.

(9) Communication equipment should be provided with emergency power. Emergency batteries and back-up engine generators are vulnerable to earthquake damage and were discussed in paragraph B-4*a*. They are often a critical element to ensure the functionality of communication equipment after an earthquake. Newer communication equipment is computer based, and the quality of emergency power may be higher than what was adequate for older systems.

e. Microwave communications system.

(1) A reliable means of communication to offsite command organizations and nearby facilities is vital. Dams usually have several means of communication to nearby facilities and the command structure. The most obvious, and the most flexible, is the public switch network telephone system. This has not been included in this section because these systems typically have traffic congestion problems and do not function well during an emergency response period. They are unreliable in postearthquake situations and should not be relied upon as the primary means of communication. Also, the Corps has little or no

control over the operation of these systems. The Federal Telecommunications System (FTS 2000) in many locations is independent of the public switch network telephone system, but this independence at some remote sites, such as dams, should be verified. Little information on problems with traffic congestion for this system is available in the public domain so these systems should not be relied upon as the primary means of communications in an emergency unless their postearthquake performance can be determined.

(2) If access to a Corps of Engineers microwave system is available at a site, it should provide a reliable means of contacting the command system. Microwave equipment at the site should be anchored. The structural integrity of the entire system should be ensured, that is, from the microphone or terminal to the antenna. Generally, microwave towers have performed well in earthquakes. Their most significant vulnerability is the disruption of commercial power and malfunction of emergency backup power sources. Anchorage issues were discussed in paragraph B-4*d*.

(3) If the microwave system is to provide the primary means for outside communications, relay towers should be provided with emergency back-up power. In addition, the system nodes should be manned around the clock so that requests for assistance or advisories can be acted upon quickly. One of the disadvantages of this system is that the number of nodes that can be accessed is limited, but hopefully these would include the critical locations. An attempt should be made to verify that there are no hidden dependencies in the microwave system. For example, some links of the system make use of the public switch network (which may not be a reliable link in a seismic event). All nodes should be sheltered in seismically adequate structures and need to have adequate, seismically secure emergency power. Emergency batteries and back-up engine generators were discussed in paragraph B-4*a*.

f. Radio system for offsite communications. A radio-based system is an alternate method for communication with offsite locations. Most of the comments about the onsite radio communications and microwave system also apply to radio systems. These systems should be adequately anchored and provided with emergency power. For additional information, see paragraphs B-4*a*, B-4*d*, and B-4*e*.

g. Miscellaneous systems.

(1) Sump pump system. The consequences of the failure of the sump pumps on system protection and safe shutdown should be evaluated. Some flooding can be expected from the failure of noncritical piping systems. If flooding resulting from the malfunction of the sump pumps would affect critical systems, the pumps should be provided with emergency power. In addition, the anchorage of the pump should be checked.

(2) Critical access roads. Situations could arise in which repair crews and materials may have to be brought into the site to mitigate a critical situation. Some damsites may be located such that landslides or bridge damage may make it difficult or impossible to respond in a timely manner. As part of the hazard evaluation, access for offsite equipment needed for postearthquake recovery of project lifelines should be evaluated. Mitigation measures to reduce this risk may be very costly, but mitigation through contingency plans that evaluate alternative sources of supply may be practical.

(3) Relays. The malfunction of a relay can cause undesirable consequences. Relays are seismically rugged so that they are unlikely to be damaged; however, the performance of the relays is subject to vibration-induced chatter. There are two broad classes of relays: protective relays and auxiliary relays. Many protective relays are inherently sensitive to vibration-induced changes of state; however, their operation will initiate an orderly shutdown sequence. Most auxiliary relays are not overly sensitive to vibration-induced chatter or change of state, but their inadvertent operation may cause inappropriate responses yielding system hang-up or damage. Chatter or change of state of most auxiliary relays will not impact system operation adversely. Checking of all relays to determine the impact of their malfunction is a costly and time-consuming task, and, in general, would not be warranted. The evaluation of the emergency power system may be justified. Some relays have been identified to be more sensitive to vibration in critical applications in the nuclear power industry.

B-5. Systems Needed for the Continued Operation of Dams

The following systems have been listed in the order of their vulnerability, taking into account their importance to continued system operation and ease of implementing mitigation measures.

a. Normal house power.

(1) House power, or station power, is usually supplied from several sources. Power is usually supplied at voltages of 2 kV or above and passes through a unit substation to supply 480 V for motors and distribution panels. House power is needed for continued operation of the dam.

(2) All components including transformers providing house power and units substations should be anchored taking into account both strength and flexibility. Frequently, transformers providing house power are not anchored (Figure B-18). Transformers should be prevented from sliding and tipping. Some units can be tall and exert large overturning moments. Frequently these units in dams are surrounded by structural walls so that restraints placed at the base and bracing to walls near the top of the unit can provide adequate seismic protection. Of particular concern, because the anchorage is concealed, are certain dry-type transformers in which some manufacturers do not positively anchor the transformer coil to its cabinet.

(3) Older medium and low voltage switchgears typically have much more substantial cabinets as compared with the same types of equipment purchased today. For new equipment, the strength and flexibility of the cabinet, particularly in the areas near anchor bolts, should be checked. It is generally difficult to install anchorage on existing equipment of this type because it is difficult to move the cabinets, and cables in the bottom of cabinets can make it difficult to even check anchorage, much less install new anchors if needed. Figure B-13 illustrates a retrofit method for this type of equipment, and paragraph B-4*f* discusses other anchorage issues. The use of bracing to the top of cabinets to reduce base anchorage requirements is another alternative.

(4) Rather than in the center of the front and back framing members, anchors generally should be placed near the side walls of cabinets because the side wall acts as a diaphragm and provides much of the stiffness of the cabinet. The load path between the wall and the anchor should be kept both strong and stiff. Anchors through folded sheet metal that form the cabinet framing at the bottom must be anchored near the wall and should have heavy washers or back-up plates under the washers to prevent the bolts from tearing the sheet metal. Welds along inside edges of sheet metal framing and the use of puddle welds in bolt holes should be avoided. Low and medium voltage switchgear tends to be quite deep so that overturning moments are relatively small. Motor control centers are typically 20 in. deep and 90 in. high so that substantial overturning moments can be applied to the anchorage. Some instrument cabinets can also be very shallow.

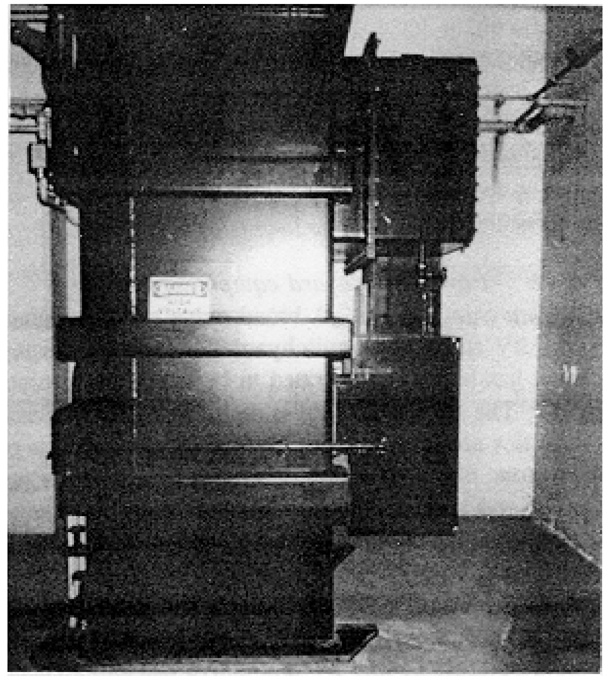

Figure B-18. House power transformers are frequently unanchored

(5) All power equipment needed to operate the turbine, such as equipment needed for field excitation, should be anchored.

(6) When house power turbines are not part of the dam's power configuration, house power is

derived from the output of some of the main turbines or off the input bus to the step-up transformers. At some dams an external line from a distribution substation of the local utility will provide power. Thus, if the step-up transformers trip off-line due to sudden pressure relays and the main turbines, which are connected to house transformers, happen to be shut off, the plant will go dark. Systems with battery or engine generator back-up power should remain operational.

b. Power switchyard equipment including step-up transformers. A broad range of high voltage (220 kV and above) switchyard and substation equipment has been demonstrated to be seismically vulnerable. The equipment that is an integral part of dam facilities are step-up transformers, lighting and surge arrestors, circuit breakers, disconnect switches, wave traps, and bus support structures and bus. The seismic performance of switchyard equipment is closely correlated with its operating voltage. Equipment with operating voltages below 220 kV, if it is adequately anchored, has performed well. Equipment with operating voltages of 220 kV and above has experienced a broad range of failures, most of which are associated with inadequate anchorage or the failure of porcelain members which are part of the equipment. Porcelain members are more vulnerable the higher their operating voltage.

(1) Power transformers.

(a) Transformers perform a vital function for which there is no substitute. Without the step-up transformers, power generated in the dam cannot be supplied to the power grid. Several types of earthquake damage or earthquake-induced responses have been observed: damaged surge arrestors associated with transformers, leaking bushings, radiator leaks, cracked bushings, damaged control cables, vibration-activated sudden pressure relays, spurious operation of mercuroid switches, failed anchorage, failed surge tank support, internal failure, and damage to tertiary bushings and surge arrestors.

(b) Inadequate transformer anchorage is one of the main causes for failure. Four general approaches are used to support and restrain power transformers. Transformers can be unanchored on a concrete pad, rail-mounted, bolted to a concrete pad, or welded to steel embedded in a concrete pad. Within each type there are many variations. Earthquake-imposed ground motions require that transformer anchorage must be able to withstand the large loads associated with transformers, which frequently weigh in excess of 500,000 lb.

(c) An unanchored transformer (Figure B-19) can slide on its supporting pad as the pad vibrates back and forth in an earthquake. This is a means of base isolation. One of the advantages of this "anchorage" approach is that the transformer experiences lower horizontal accelerations than it would had it been fixed to its support pad. This would reduce inertial forces on bushings, radiators, and internal components.

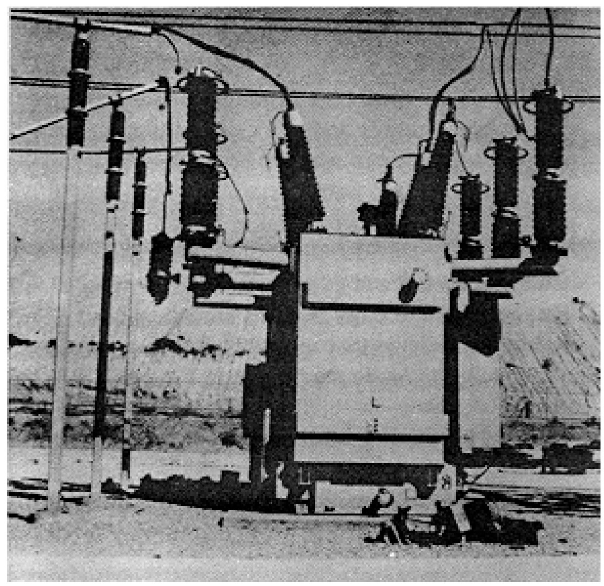

Figure B-19. Unanchored transformer. Sliding of an unanchored transformer caused one surge arrestor to fail. Several bus connections to bushings and surge arrestors also failed. The failure of the bus connections probably prevented surge arrestor and bushing damage

(d) There are several reasons why this approach is not recommended. There is no way to predict the motion of the transformer relative to its support pad. A transformer with permanent movement of almost 3 ft has been observed in a moderate earthquake. If there is slight differential settlement of the foundation pad, very large motions may occur when the transformer slips off of its sloping pad. Large motions can damage bus connections or the porcelain members to which the bus is connected.

(e) Long vertical drops using flexible bus can accommodate relatively large displacements, but short flexible bus connections between equipment, rigid bus connections, and control cable connections to the transformer can only accommodate limited motions (Figure B-20).

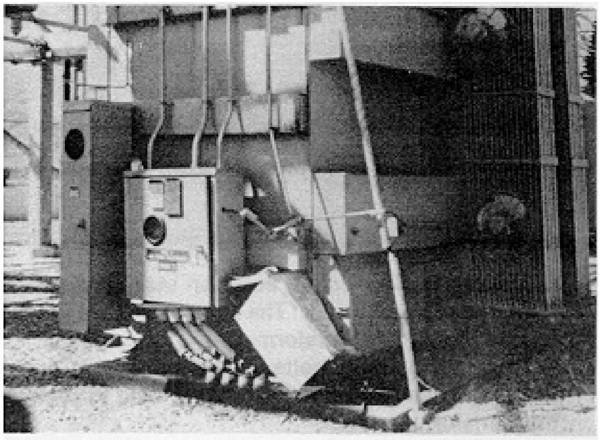

Figure B-20. Transformer control cable damage. Sliding of an unanchored transformer has damaged control cables and piping penetration allowing transformer oil to leak

(f) Pad supported transformers can be anchored to plates that are bolted to the pad and then welded to the transformer body. The design should ensure the earthquake-induced inertial forces can be transmitted to the pad without permitting unacceptable distortion or creating a brittle failure mechanism due to prying action between the connection and the anchor bolt.

(g) Rail-mounted transformers are frequently supported on top of pedestals to accommodate a cart on rails running transverse to the row of transformers. Chocks used to restrain the rail-mounted transformer are not very effective as they tend to be pushed off the end of the rail (Figure B-21). Even if the chocks restrain the transformer, the transformer can tip over in a lateral direction as there is no vertical restraint. When pedestal-mounted transformers fall, they can severely damage radiators, bushings, surge arrestors, bus and control cable connections, piping connections if they are water cooled, and the bus support structure. Major, lengthy repairs are usually required.

(h) The design of retrofits for rail-mounted transformers must carefully consider the load path. In general, it is desirable to anchor the transformer to

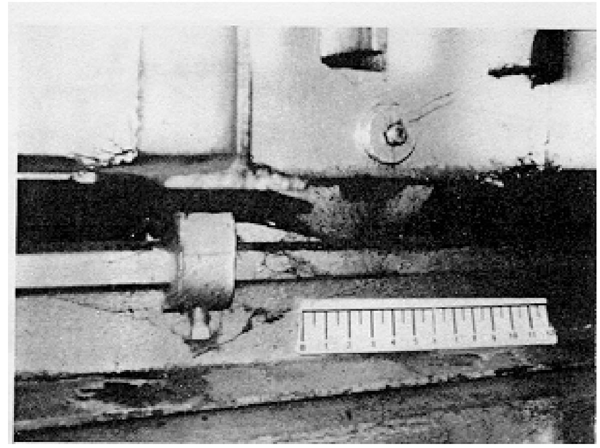

Figure B-21. Transformer restrained by chock at dam. A chock, clamped to a rail, restrains a pedestal-mounted step-up transformer at a dam. This type of restraint has repeatedly proven to be an inadequate anchorage

the support pedestal or pad rather than to the rails (Figures B-22 and B-23). If the transformer carriage is anchored to the rails, the stability and strength of rail anchorage must be considered. The transformer must also be securely anchored to its carriage (Figure B-24). Because of the wide variation in rail support configurations, most retrofits must be specially designed.

(i) Figure B-25 shows a close-up view of the inside of a wheel housing and concrete key. There is a very small gap between the key and the wheel housing and the key has a large angle forming its upper corner. This procedure eliminates the need for the rails to carry lateral loads, but still lacks positive vertical restraint. The side of the chock is secured to the rail by 1-in. bolts. The chock is secured to its side supports by a single 1-in. bolt. Note that the chock is cut to fit the curvature of the wheel and extends about two-thirds of the way to the axle. The massive wheel support has large gusset plates and is bolted to the carriage. The carriage is welded to the base of the transformer, ensuring a good load path between the wheel and transformer.

(j) The recommended method of transformer anchorage for new construction is to weld the transformer case to a steel embedment in the foundation pad. It is important that adequate weld length be provided to carry the maximum expected loads and that good weld penetration be achieved. The embedment must also be properly designed and installed.

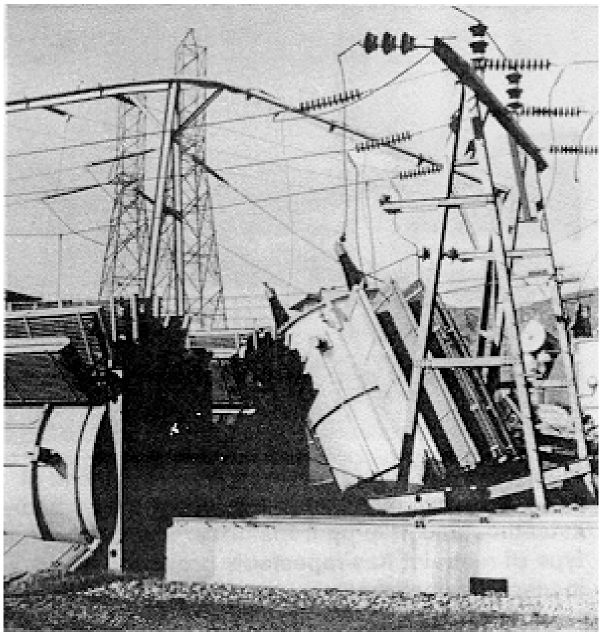

Figure B-22. Failure of rail-mounted transformers restrained by chocks. Five of the six single-phase transformers fell from their supports, damaging radiators, bushings, and the bus support structure. Chocks clamped to the rails could not restrain the transformers. Restoration is lengthy and expensive. Note that the carriages on the 2nd and 3rd transformers separated from their transformers

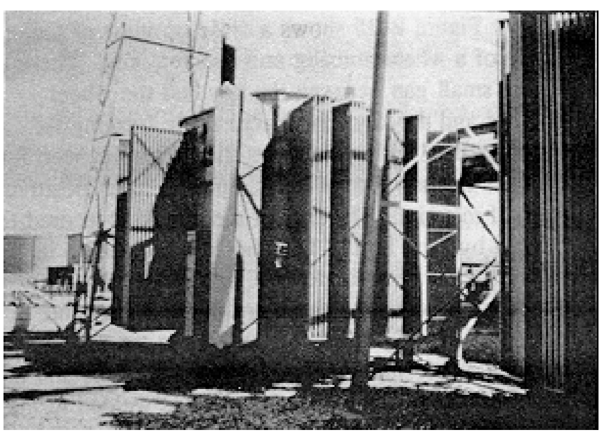

Figure B-23. Transformer restrained to rails. Overall view of rail-mounted transformer which is restrained by large chocks and concrete keys under the carriage. Note that the rails are mounted to a slab at grade; however, the transformer has no positive vertical restraint. Since the unit is not mounted on an elevated pedestal, it is less likely to fall over

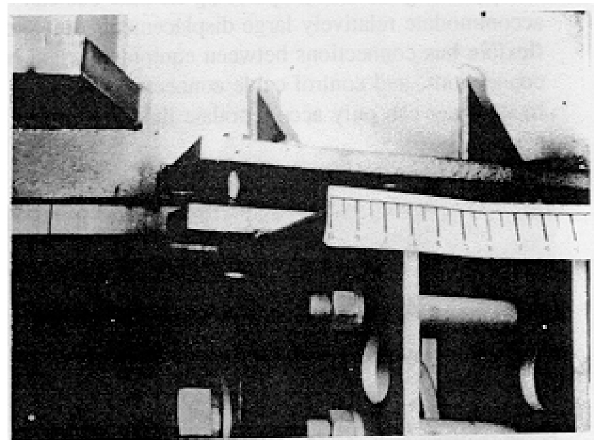

Figure B-24. Connection between step-up transformer and its carriage. The transformer carriage is attached to the transformer at four locations, each with two 1/2-in. bolts. If the carriage is not adequately anchored, it may not be able to restrain the transformer

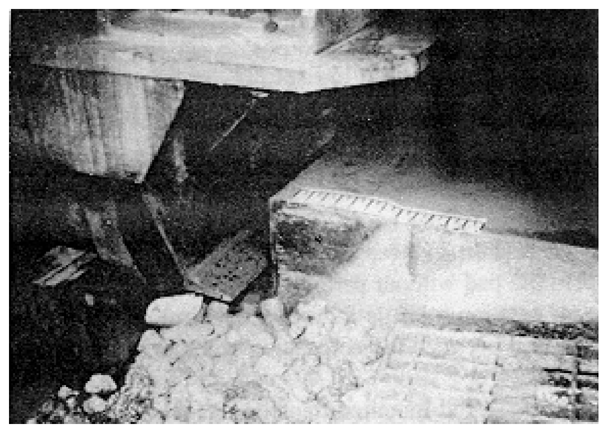

Figure B-25. Wheel restraint detail

The advantages of this method of attachment are that no failures have been observed with well-designed embedments, and transformers are rigidly held to the foundation pad so that lift-off and subsequent impact are avoided. Impacts introduce large accelerations that can damage porcelain and bushing seals, and subject internal components to large forces. Another advantage of embedments is that problems with prepositioning cast-in-place anchor bolts are eliminated. Also, should the transformer need to be changed, and oversize embedments were used in the initial design, welds on the original transformer can be burnt off

and new equipment installed without modifying the foundation pad.

(k) The thickness of the embedment must be adequate so that welds will not tear out of the material and that loads transferred through the weld can be distributed to several of the bolts or hooks that transfer the load to the concrete. It is desirable that the embedment extend beyond the weld so that good load transfer is made to the concrete. Embedment capacities should be based on headed studs or hooks and not on bonding between the embedment plate and the concrete. There should be adequate edge distance between the embedment, and the pad boundary and the placement of rebar between the pad edge and the embedment should be considered.

(l) Some step-up transformers at dams are water-cooled rather than air-cooled. Movement of the transformer can cause the failure to piping connections associated with the cooling system (Figure B-26).

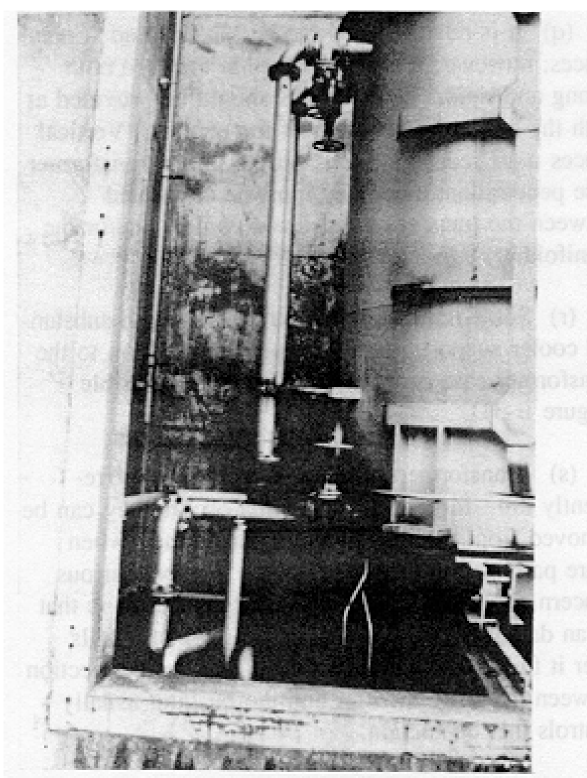

Figure B-26. Piping connections of water-cooled transformers. Relatively rigid piping connections in water-cooled, chock-restrained transformers are one of the main restraints to transformer motion. Relatively small movement could cause pipe flanges to leak

(m) Transformer coolers, depending on their design, are vulnerable to oil leaks. Large coolers that are manifold-mounted are the most vulnerable. Typically, the upper structural support of the cooler is the penetration through the transformer case (Figure B-27).

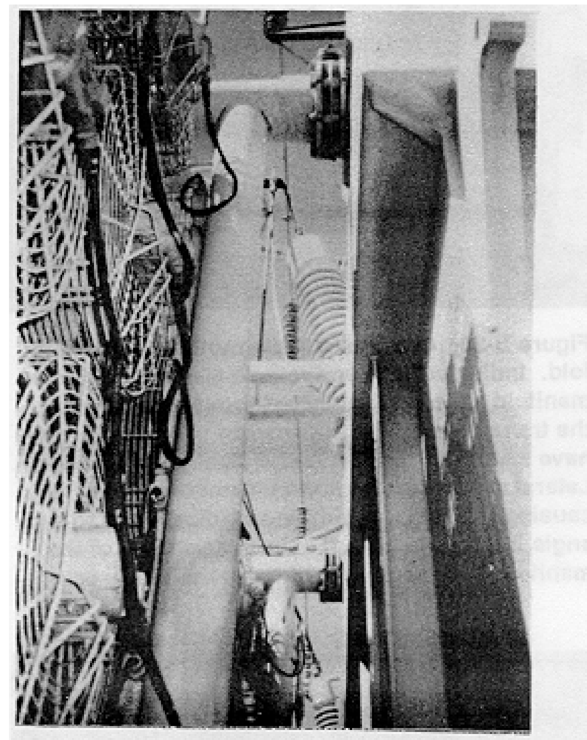

Figure B-27. Upper cooler support and transformer penetration. A large manifold-mounted cooler is supported by the pipe that also serves as the penetration to the transformer case. Lateral forces can cause large moments on the flange and oil leaks

(n) Transformers at a dam are vulnerable to oil cooler leaks. Oil coolers with or without inadequate vertical and horizontal bracing have developed leaks at the flange connecting the coolers to the transformer body (Figure B-28).

(o) When the lower penetration through the transformer case serves as the primary support, it also has a tendency to develop leaks (Figure B-29).

(p) Coolers which are individually connected to the transformer by their own penetrations have not developed leaks (Figure B-30).

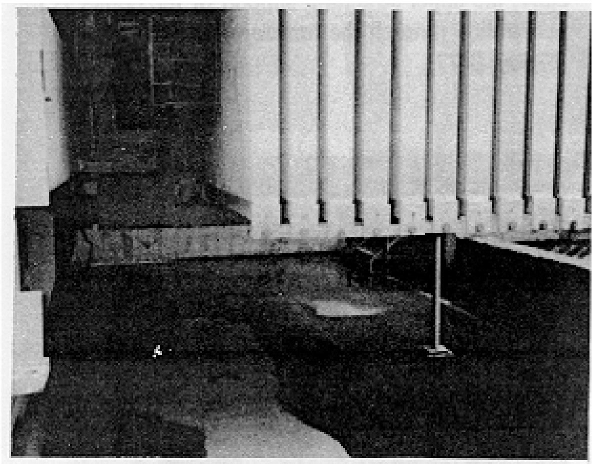

Figure B-28. Cooler elements mounted to a manifold. Individual cooler sections are mounted to a manifold which is connected to a flange forming the transformer case penetration. The cooler does have a vertical support and a small diagonal brace. Lateral motion exerts large moments on the flange causing oil leaks. A simple modification is to add angle iron brace between the outside end of the manifold and the corner of the transformer case

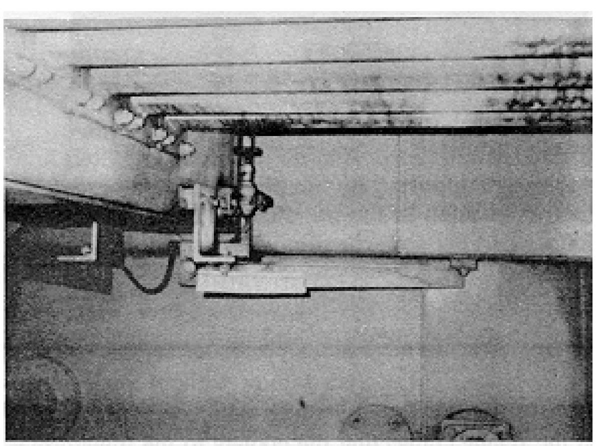

Figure B-29. Bracing of lower cooler manifold. A diagonal angle iron serves as a brace between the transformer body and the cooler manifold. Note that the connection to the manifold is through an angle. While this may be strong, it is very flexible so that the cooler assembly is not adequately restrained, and large moments can be applied to the flange on the transformer case penetration

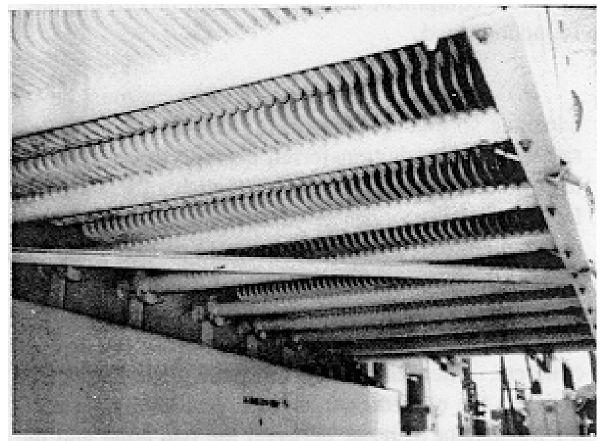

Figure B-30. Individually supported cooler elements. Each cooler element has its own transformer case penetration which also serves to support the cooler. Flange leaks have not been observed for this type of configuration. The end of the coolers which is most distant from the transformer body is also restrained by a small angle iron brace

(q) It is relatively easy to add lateral and vertical braces; however, it is important that they are both strong and rigid. These braces should be provided at both the bottom and the top of the coolers. Vertical braces must reduce the load on the upper transformer case penetration; thus, they must be connected between the transformer case and coolers and/or the manifold.

(r) Some transformers are designed with substantial cooler supports, and the piping connection to the transformer case penetration is relatively flexible (Figure B-31).

(s) Transformer-mounted surge arrestors frequently fail. In general, when this occurs they can be removed from the system and replaced later when spare parts and time are available. A more serious concern about the failure of the surge arrestor is that it can damage a transformer bushing when it falls after it fails. The configuration of the bus connection between the surge arrestor and the bushing usually controls this interaction.

(t) Oil leaks at bushings and, less frequently, bushing failures can put a transformer out of service. At this time there is no effective remedy for this,

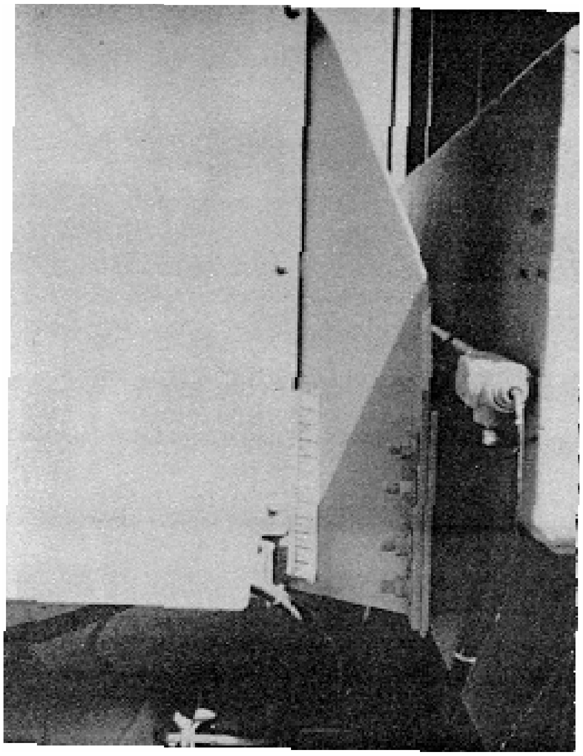

Figure B-31. Manifold-mounted cooler with support structure. The cooler lower support is substantial and separate from the piping penetration. The connection to the transformer case penetration is relatively flexible to reduce moments applied to the pipe flanges

although performance should be improved by anchoring transformers and providing slack in flexible bus so that relative motion between adjacent equipment items can be accommodated without overloading porcelain elements.

(2) Circuit breakers.

(a) Switchyard circuit breakers play an important role in system protection. They can be bypassed if desired but with reduced system protection then provided by other circuit breakers. Their seismic shock integrity depends upon design. First, existing oil circuit breakers are seismically rugged. However, they are being replaced with SF_6 circuit breakers which need less maintenance and are less of an environmental hazard. Live-tank SF_6 circuit breakers are seismically very vulnerable (Figure B-32). If used, they should be designed for seismic forces. Dead-tank SF_6 circuit breakers should be considered for replacements because of their inherent seismic ruggedness.

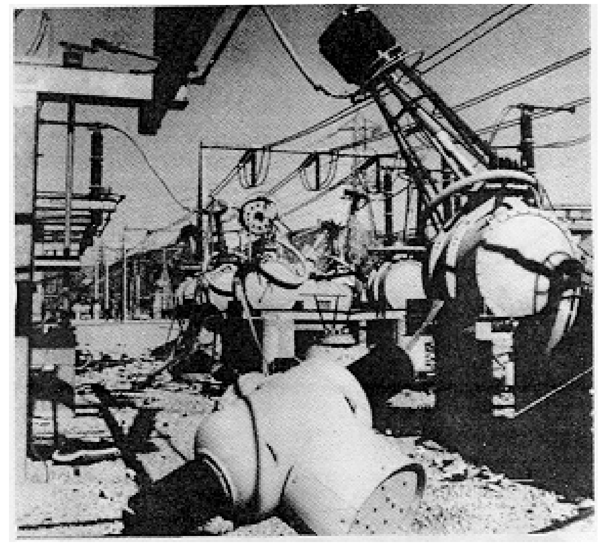

Figure B-32. Earthquake damage, live-tank circuit breakers. The porcelain columns that support the interrupter heads on life-tank circuit breakers are very vulnerable

(b) The three phases of bulk oil circuit breakers are typically welded to a fabricated base, which is often anchored with friction clips. The use of friction clips doubles the anchor bolt load, and the clips tend to rotate around the bolt allowing the circuit breaker assembly to move in an earthquake. A simple fix is to weld the end of the friction clip to the circuit breaker frame.

(3) Disconnect switches.

(a) Disconnect switches are used to reconfigure power system elements. If damaged, they can usually be temporarily, and quickly, bypassed.

(b) Post insulators used to fabricate disconnect switches have failed. Their failure can cause more severe problems after they fail when they are located on bus structures or otherwise supported above circuit breakers or transformers, as falling parts from the switch can damage bushings (Figure B-33). The risk of these failures is relatively small so that retrofitting is probably not justified. For units that present an unacceptable risk, the post insulators can be replaced with units made of high strength porcelain. In new

construction, good system layout can reduce the risk of secondary failures.

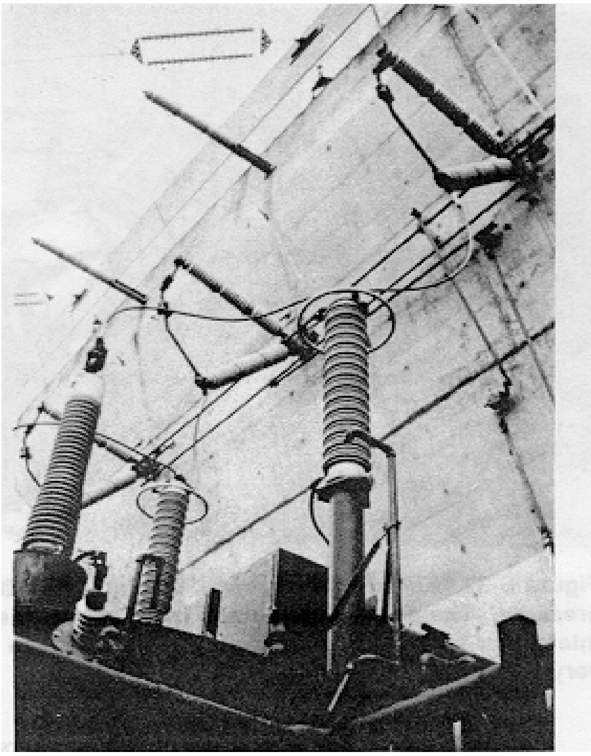

Figure B-33. Disconnect switches located above transformer bushings

(4) Other switchyard equipment.

(a) There are many other types of high voltage switchyard equipment that are seismically vulnerable. These include current-voltage transformers, current transformers, and large, porcelain-supported wave traps. These types of equipment do not appear to be used at damsites and will not be discussed in detail. Their seismic performance can be improved by limiting the relative motion between adjacent equipment items or providing bus connections that can accommodate this motion. High strength porcelain can also be used.

(b) Bus configurations may be vulnerable to earthquake damage. In one case, a taut bus from near the step-up transformers to the top of the bus support structure on top of the power house could be subjected to high loads if the bus support structure moves (Figure B-34). A small amount of slack would eliminate the problem.

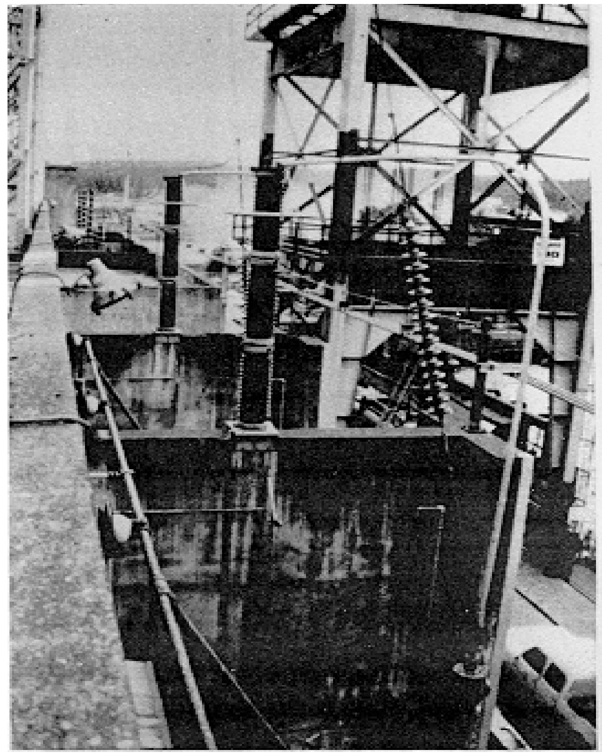

Figure B-34. Vulnerable bus runs

(c) A strategy used by some utilities to improve seismic response of substations known to be vulnerable is to identify and seismically “harden” a critical path so that acceptable performance can be maintained. An example of hardening would be to replace vulnerable live-tank circuit breakers with seismically rugged dead-tank circuit breakers at critical locations to ensure the integrity of the circuit. While this is an effective procedure for substations designed with some redundancy and flexibility, the relatively simple design of high voltage elements associated with dams does not lend itself to this approach.

c. General equipment.

(1) Many types of equipment are needed for continued operation of a dam: unit substations; motor control centers; motors; fans; pumps; tanks; piping systems; air- and motor-operated valves; heating, ventilating, and air conditioning systems; fire suppression systems; control consoles; etc. (Figure B-35). In general, these items are seismically rugged, primarily because they have survived shipping loads. Some items, such as pumps, have service loads that are more severe than seismic loads. The seismic

performance of these systems is primarily governed by the adequacy of component anchorage. Issues related to anchorage have been discussed earlier. Some equipment, such as air conditioners and fans, may have vibration isolators incorporated into their design. Seismically induced motions to these isolated systems may cause misalignments, impacting, or binding of moving parts. Small air- and motor-operated valves supported by the piping system may experience significant amplification due to seismically induced motions. These components are quite rugged, but control lines (either air or electrical) connected to the operating device must be provided with sufficient slack to accommodate the motion of the piping system. Some failures have occurred when inadequate clearance was provided around the devices so that they were damaged when they impacted other equipment or the structure when the piping system moved.

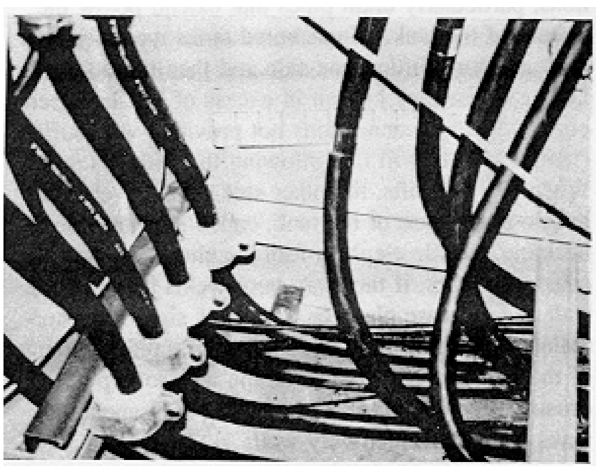

Figure B-35. Control console anchorage. Control consoles should be securely anchored. This console in a dam is anchored with friction clips, which can slip

(2) Heating, ventilating, and air conditioning systems, if properly anchored and braced, perform well during earthquakes. The Sheet Metal and Air Conditioning Contractors National Association has guidelines for the design of seismic restraints for mechanical and plumbing piping systems.

(3) Fire protection systems installed under National Fire Protection Association (NFPA) 13, will have adequate seismic protection.

(4) Although cranes can be derailed or overturned due to earthquake ground motions, this usually occurs on soft soil sites where ground motion amplification or soil failures occur. Cranes on hydroelectric power projects are rugged and not expected to experience damage due to earthquake ground motions.

(5) Critical spare parts, such as bushings, should be anchored to substantial racks that are anchored and safe from secondary damage (Figure B-36).

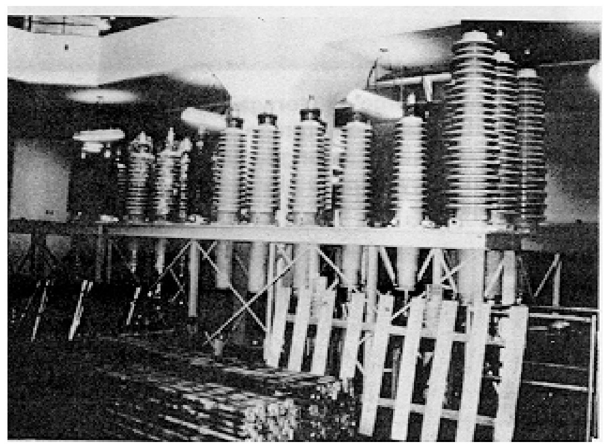

Figure B-36. Storage of critical spare parts

d. Generator thrust bearing lubrication system. The continued operation of the main thrust bearing lubrication system is vital. The integrity of the piping system and pumps is necessary. As noted earlier, piping is seismically rugged if heavy components, such as tanks, are well anchored (Figure B-37). Components in the power supply must also continue to function. Thus, unit substations and motor control centers must be anchored. Comments contained in paragraph B-5*c* also apply to this system.

e. Generator bearing lubrication oil cooling system. The continued operation of the turbine bearing lubrication oil cooling system is required (Figure B-38). The comments in paragraph B-5*d* also apply to this system.

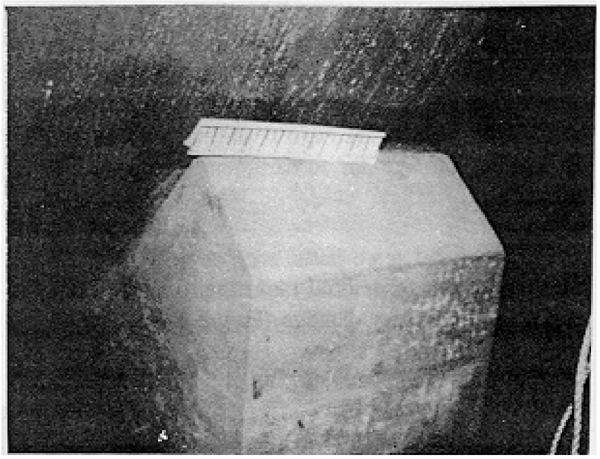

Figure B-37. Large oil storage tank inadequately anchored. A large oil storage tank does not have positive restraints for longitudinal motion. Motion of the tank may damage pipe connections and cause a leak

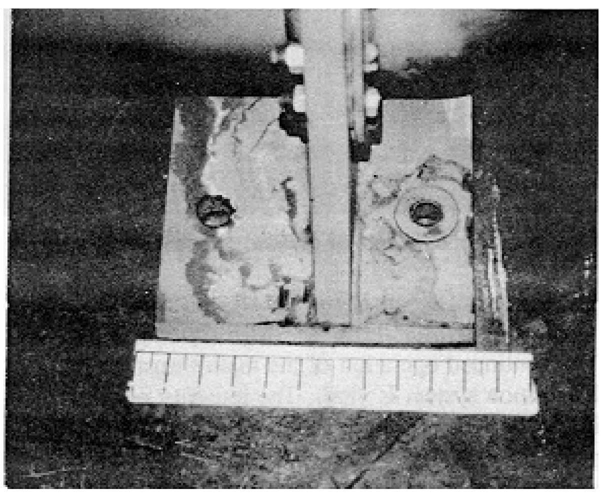

Figure B-38. Unanchored chiller. In large facilities, such as a dam, when some equipment was initially installed, modified, or replaced, it may not have been adequately anchored. A walk-through of facilities will usually find unanchored equipment

f. Water used for air conditioning needed to maintain computers or communications systems.

(1) The water supply system is frequently used to cool air conditioning systems needed for computers and communication systems. The water system elements are pumps (and their power supply and control system) to draw water from wells or the river, tanks to store the water, and a piping system connecting the system elements and to bring the water into the facility.

(2) As noted earlier, pumps are seismically rugged; however, wells are vulnerable to sanding of their intake screens and damage to casings and bindings of the pump drive due to deformations from soil liquefaction. Soils around the damsite are likely to be very vulnerable to soil liquefaction and subsidence.

(3) One of the most common failures observed in earthquakes is water tank damage, primarily to unanchored tanks. A problem common to most tanks is damage to the roof due to sloshing of water in the tank. This may buckle the roof and tank wall near its top, but usually does not impair the functioning of the tank. Unanchored flat-bottom tanks have several failure modes. Smaller tanks (less than about 30 ft in diameter) may slide. This may break piping connections, particularly drain pipes that extend below the bottom of the tank. Unanchored tanks typically rock back and forth lifting one side and then the other. Lifting of the tank bottom in excess of 2 ft has been observed. Pipe connections not provided with sufficient flexibility will fail, allowing the tank to drain. When one side lifts, the other side often develops a buckle at the base of the tank, called elephant-foot buckling. While elephant-foot buckling may not cause any leaks, if there are poor welds between the wall and the base plate, or if there is significant corrosion, welds will fail. This allows a rapid emptying of the tank and usually causes the tank to explode, causing severe damage to the tank. Well-anchored tanks have performed very well.

(4) The most vulnerable part of the water system is the piping that connects the wells, tanks, and user facilities. Water pipes, which usually use bell and spigot or rubber gasket seals to join pipes, are vulnerable to soil liquefaction and subsidence. Key to the continued functioning of the stem is a carefully planned series of valves to sectionalize the system so that damaged parts can be isolated to prevent them from causing a loss of pressure and water. Large water systems can drain in a matter of minutes with just a few failures. One location of particular concern is where the water system pipes enter the structure, as subsidence around the structure may cause failures where there is limited redundancy.

g. Computer systems.

(1) Computer systems generally play a vital role in system operations. This is especially true during an emergency when major changes (generator separation from the power grid may require that all turbines be immediately shut down) in the operation of the system may be required, and several other systems may be impacted by the effects of the earthquake.

(2) In general, the seismic performance of computers has been good. Systems should be anchored, an uninterruptable power source should be provided for their continued operation, and air conditioning should be provided, where needed. When air conditioners are required, they must be provided with emergency power, and, in some systems, a water supply. The most vulnerable elements are terminals and display units, which are often unanchored or inadequately anchored. They are frequently damaged by falling from desk tops or control bench tops to the floor. The anchoring of computers on elevated computer access floors must be done with special care.

h. Communications system for power network dispatching. Power dispatching for dams is very different than for other power-generating plants used by the power industry. Power dispatch for most power plants is done via computer control and is updated several times a minute. The dispatch for dams is typically done on an hourly basis. For dams, an overriding consideration for the release of water is associated with river flow control. This can be governed by many factors, such as interaction of water release from a series of dams on a river, environmental issues related to fish in the river system, reservoir water levels, and river flow rates. These requirements, along with power-generating needs, must be integrated into power grid operations.

i. Internal telephone system.

(1) The internal telephone system provides communication within the site and is a link to the outside. The core of the system is usually a private branch exchange (PBX) that serves to connect internal calls and is the junction to the public switch network through lines from the local telephone company central office. In some cases, instead of a PBX, a Centrex system may be used. That is, internal calls are completed by means of the switch located at the telephone company's central office.

(2) The PBX should be anchored and provided with emergency power (Figure B-39). These systems are typically stand-alone units and seldom exceed 6 ft in height. Their basic seismic ruggedness will be a function of the manufacturer and the age of the equipment. New equipment from the major manufacturers typically incorporates good seismic design features; however, units must be anchored and provided with back-up power. Older units and units from smaller companies may not be constructed with the same seismic details. The main vulnerabilities are the lack of positive restraints to prevent circuit boards from vibrating loose, and the strength of cabinets, particularly in the area near anchor bolts.

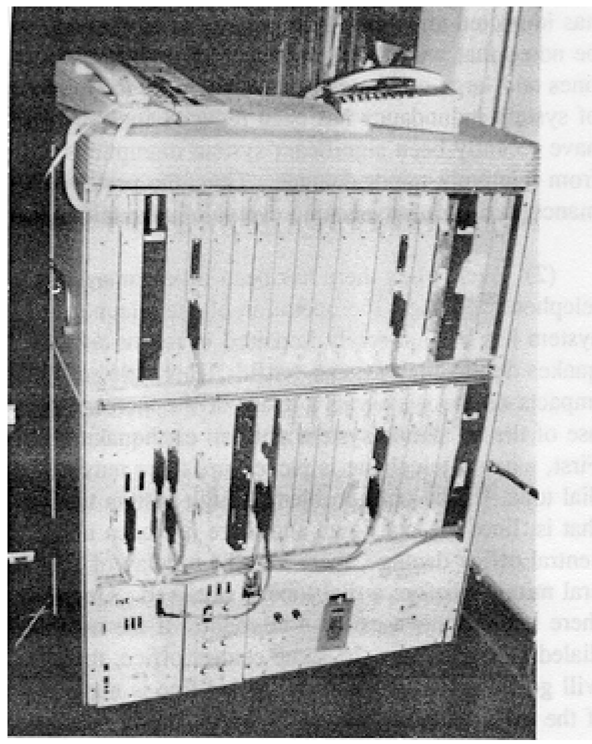

Figure B-39. Unanchored PBX used in a dam. This PBX has been designed to resist earthquakes. The circuit cards are latched in their card cages, and the power supply, which is relatively heavy, is located at the bottom of the unit to keep the center of gravity low. The unit is unanchored so that connecting cables can be damaged if it moves in an earthquake

(3) Use of a Centrex system has many advantages, such as selection of system features, maintenance personnel always on duty, and system

flexibility. However, in the aftermath of a damaging earthquake, high telephone system traffic may severely impair the operation of the system. For example, it may be difficult to call an office down the hall, as all calls must go through the telephone company's central office.

(4) Other communication system issues are discussed in paragraph B-4*d*.

j. External public switch network telephone system.

(1) The seismic performance of public switch networks, from a facilities point of view, has been very good. There has been very little damage that has impacted telephone system operations. It should be noted that with the introduction of optical fiber lines and large computer-based switching, the degree of system redundancy has been reduced and there have recently been significant system disruptions from relatively minor damage. Thus, the performance during future seismic events is uncertain.

(2) Even when there has been little damage to telephone facilities, the operation of the telephone system has been severely impaired in recent earthquakes due to high system traffic. There are several impacts on the system as a result of the increase in use of the telephone system after an earthquake. First, when a telephone is picked up, there may be no dial tone. If the only problem is high system traffic, that is, lines are not down and there has been no central office damage, there may be a delay of several minutes before a dial tone is obtained. Once there is dial tone, a call can be made. If the number dialed is serviced by the same central office, the call will go through quickly if the called line is not busy. If the party called is serviced by a different, nearby central office, the call will probably not go through due to busy telephone trunks. If the call is to a distant party so that long distance service is needed, the call will probably not go through due to busy telephone trunks. Long distance calls coming from outside will have even a smaller chance of getting through. Busy telephone conditions can persist for several days following an earthquake.

(3) A special grade of service is available to certain customers, and some lines to a dam should qualify. This is usually referred to as an essential service line. Some companies refer to this as class A service. With this service, the line should be given priority in getting a dial tone. This will give the caller access to the local central office. If the call is to another central office or if it is a long distance call, it will have no special priority.

k. Miscellaneous systems. There are two systems associated with dam facilities that can impact system operation, suspended ceilings in control rooms, and elevators, which although are not vital to continued operations, can impact the postearthquake response.

(1) Suspended ceilings in control rooms. Failure of the control room ceiling can disrupt operations during critical moments after an earthquake. The most vulnerable type of ceiling is the "T" bar suspended ceiling. While new building codes have reduced the problems, older systems have completely failed, and large numbers of panels and light fixtures frequently fall. If the acoustical tile panel is lightweight, it may not cause a problem, but falling light fixtures can cause severe injuries and damage the control panel. Even ceilings designed to the new codes often drop a few panels, particularly around the periphery of the room, and air diffusers can fall.

(2) Elevators.

(a) While elevators are not necessary for the continued operation of a dam, if there are problems and repair crews need to respond quickly, functioning elevators are important.

(b) The seismic performance of elevators has been poor. The most severe problems are lack of anchorage of machine room equipment, including control cabinets, motors, and the traction machine. A common failure is the counterweight coming out of its rails. If this happens and the elevator is used, the counterweight, which can weigh 6,000 lb can strike the cab. Counterweight derailment has been associated primarily with the use of 8-lb guide rails. However, in general, the problem is with flexible rail supports or supports that are too far apart, rather than with the rails themselves.

(c) Machine room equipment should be anchored, and if the counterweight system appears vulnerable, stiff counterweight rail tie brackets can be added. Guidance for upgrading can be obtained from ANSI A17.1, National Elevator Code.

l. *Black start capability*. Most Corps powerhouses are designed with a black start capability (the ability to start a cold generating unit with the loss of offsite power). Many generating units, if they are down less than 2 days, may be able to start. If there is adequate reserved compressed air in the turbine governor system to open the gates, turbines can be started. If the units were operating within the previous 2 days, there should be enough of an oil film on the main thrust bearings to prevent damage. Typically, residual magnetism in the excitation field is adequate to start power generation. A true black start capability requires power for main bearing pumps, field excitation, and power to pressurize the governor system. Consideration should be given to adding black start capability to powerhouses that do not have this capability.

B-6. Disaster Response Plans and Their Exercise

a. Earthquake preparedness measures to improve the earthquake response of dams fall into two categories, mitigation measures and emergency response measures. Mitigation measures can be divided into three tasks: river control aspects, control of factors that would cause major system damage, and measures that would improve the ability to continue to provide power. The latter two have been discussed in paragraphs B-4 and B-5. The former requires a review of central river dispatch procedures and facilities and is outside the scope of this report.

b. The key to effective disaster response plans is the acknowledgment of the importance of the issue and commitment by top management. Most lifelines have emergency response plans and they are occasionally put to the test by various conditions such as severe floods or storms. Earthquakes pose a special problem because they typically impact systems in unique ways such that there is little or no experience with them. In addition, earthquakes tend to impact many systems at the same time with no warning, unlike many other emergencies which can be anticipated.

c. One important issue for disaster planning is preallocation of responsibilities and authority in the event that communications are disrupted. The process of developing a plan (the identification of key issues, working through contingencies, and clarifying the roles of operating personnel) is the main benefit rather than the actual plan. This process can identify deficiencies, many of which can be addressed. Once a plan is developed, it is important that it be exercised in a realistic manner. Key to an effective emergency response is a functioning communications system. Many of the most important disaster planning issues are above the authority of a single dam, so that a general plan that involves the entire command structure should be developed.

d. For a dam, disaster response procedures are related primarily to getting off-duty personnel back to the site, even if they are not called, as communications will probably be disrupted. It is important for operators to know what the impact of a large earthquake is likely to be so that they can plan in advance the types of actions that may be needed, such as what systems should be checked. Provisions should be made for personnel at the dam to find out the status of their families. An exercise at a dam, in which a realistic scenario is given, can improve a seismic response should it be needed.

B-7. Recommendations

Recommendations are as follows:

- Most of the review was devoted to equipment needed for the operation and control of dam facilities. Little time was spent reviewing dam operating procedures. Additional evaluation effort should be directed at operating procedures to ensure that all critical systems have been considered and to better identify system interactions and interdependencies.

- Issues related to the emergency response need a more thorough investigation into the operation and control of dam facilities. This section should be expanded.

- Systems and equipment discussed in paragraph B-4 should be reviewed and mitigation measures given high priority. Earthquake preparedness measures, mitigation measures, or appropriate emergency response plans should be put in place to reduce the risk for major damage or loss of system control. Of particular concern are vulnerable key systems needed for the protection and safe shut-down of the dam--the anchorage of emergency

batteries and generators. Fortunately, many of the mitigation measures can be done at low cost if key elements are identified and standard fixes or procedures are developed for the entire system. While not all system and equipment configurations can be anticipated, the majority of the potential problems can probably be mitigated in this way.

- Systems and equipment discussed in paragraph B-5 should be reviewed and implemented when practical. The priority would be determined by the need for continuity of power generation.

- The evaluation of seismic vulnerabilities should be made by means of a facility walk-through. While personnel at each facility could use the guidelines to do an initial walk-through, each facility should be reviewed by an individual or small group of individuals with experience in evaluating facilities. The expert review could be done by an individual from within the Corps or from outside personnel. The evaluation guide can be useful for evaluating systems, but it is not a substitute for an individual with broad experience in the evaluation of seismic vulnerabilities.

- The use of informed engineering judgment in the evaluation and retrofit of facilities is suggested rather than a formal risk analysis approach. By using this approach, it is possible to implement significant improvements in seismic performance for what it would cost to just formulate and execute a formal risk analysis.

- Independent, redundant sources of emergency power for critical systems needed for the control and shutdown of the dam should be considered.

- It would be desirable for the Corps to adopt a primary communication system for all Corps facilities so that seismic consideration could be applied uniformly. For example, nodes would be located in seismically adequate structures, emergency power would be available, and the facilities would be manned at all times.

- If they are not already in place, essential service telephone lines (class A service for some telephone companies) should be requested for some of the commercial telephone lines that service the facility. These lines should be identified, and a procedure for accessing them through the PBX at the damsite should be established.

- If water for vital services is needed at a facility, such as for air conditioning of computers, the vulnerability of the water system should be assessed. The high potential for liquefaction resulting in the damage of outside plant water lines means that special attention must be paid to valves to isolate damaged parts of the system to ensure that water can be delivered to the facility.

- Dam operators and other plant personnel are a valuable resource in determining priorities for mitigation measures. In the course of the review, for many of the systems which were pointed out as being vulnerable, plant personnel indicated that the system had failed in the past and that they had “worked around” the problems associated with their failure. In the cases cited, the various problems arose, one at a time, when overall system operations were undisturbed. An earthquake may cause several of these systems to fail or malfunction at the same time that the generators are isolated from the power network. The control of the dam under these conditions may present significant problems. Past earthquake experience has also indicated that unanticipated events occur that can further exacerbate emergency response actions. While dam operators are the best qualified to control the dam under adverse conditions, and their input is needed in determining which systems should be given highest priority for mitigation, the types of disturbances that can be brought about by an earthquake are outside most operators’ experience. It is vital that operators understand the complexity of the earthquake scenario in assessing the importance of various systems on dam performance.

- Materials that are currently being prepared by the American Society of Civil Engineers Technical Council on Lifeline Earthquake Engineering for the seismic evaluation of power systems and other materials under development for the Electric Power Research Institute for the seismic evaluation of substation should be referred to when they become available.